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THE UNIVERSITY OF ALBERTA

SLOPE STABILITY IN THE NORTH SASKATCHEWAN RIVER VALLEY

BY

© KENNETH H. TEDDER

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

DEPARTMENT OF GEOLOGY

EDMONTON, ALBERTA
FALL/1986

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

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ABSTRACT

Slope movement inventory mapping and the development of set-back guidelines provide useful references for engineering projects and land use planning in urban areas centered along river and tributary creek valleys. This thesis presents a slope movement inventory and establishes set-back guidelines based on the ultimate angle of stability theory, for the North Saskatchewan River and tributary creek valley slopes located between the expanding urban areas of Edmonton and Fort Saskatchewan.

A total of 45 slope movements along the North Saskatchewan River valley are mapped and described. Of these, 31 provided evidence of their probable type of movement and the position of the rupture surface. The most common type of movement is a block translational slide involving overburden soils, followed in frequency by compound rotational-translational movements along the overburden-bedrock contact or weak planes in the Upper Cretaceous strata, and flow movements resulting from seepage and gully erosion.

Along the tributary creek valleys, older inactive-mature movements form a majority of slopes, while active translational slides are occurring on the lower half of those slopes being undercut by lateral creek erosion.

There are four main factors affecting slope stability in the study area; 1) the occurrence of Upper Cretaceous strata and associated weak planes in the valley slopes; 2) the occurrence of Saskatchewan sand and gravel in the valley slopes; 3) the action of lateral river erosion; and 4) man's activities.

The effect of urban development is shown by the occurrence of all but one of the flow movements on valley slopes below existing homesteads or farmsteads and the fact that the initiation of these flows usually coincided with the construction of the houses and farm buildings.

In establishing set-back guidelines, a comparison of the ultimate angle of stability to the inclination at their toe of oversteepened slopes which have occurred along the river or creeks provides an estimate of their potential, long term regression. Due to repeated cycles of movement and oversteepening by toe erosion the inclination of these slopes is always steeper than their ultimate angle of stability. An empirical estimate of the ultimate angle of stability is obtained from the average inclination of abandoned valley slopes which occur above the low level terraces along the river valley, as these slopes have undergone long term degradation through weathering, erosion and repeated movements over the past 8,000 years. Hence, a comparison between the inclination of the abandoned valley slopes and oversteepened slopes with similar stratigraphy and groundwater pressure conditions provides an estimate of potential, long-term regression.

Set-back guidelines of 0.7 to 3.2 times the valley depth have been established for the oversteepened slopes in the study area by adding a conservative estimate of net lateral river erosion to the potential, long term regression. The estimated rate of erosion applied is 15 m/50 years determined from measurements on airphotos dating back to 1924 and survey plans dating back to 1883 and from a comparison with previous river erosion estimates for the Edmonton area.

Flows are excluded from this procedure as they are hydraulically governed and their movement is independent of stratigraphy and groundwater pressure conditions. For these movements set-back guidelines have been established with an estimated yearly rate of valley crest regression, measured from airphotos dating back to 1924, added to the net lateral river erosion.

As the inclination of the abandoned valley slopes is considered to approximate their ultimate angle of stability these slopes should not undergo further regression with a continuation of existing loading and groundwater pressure conditions. However, to accommodate the potential effect of urban development a minimum set-back guideline is applied to these slopes. This guideline is based on the maximum amount of valley crest regression which has resulted from active slope movements over the study area in the past 60 years.

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CHAPTER 1

INTRODUCTION

In April, 1983, the Land Use Branch of Alberta Environment requested that the Geotechnical Branch undertake a study to provide an inventory of slope movements and establish set-back guidelines for the Edmonton-Fort Saskatchewan Restricted Development Area which encompasses the North Saskatchewan River valley and portions of the adjoining tributary creek valleys northeast of Edmonton. The set-back guidelines are required for preliminary land use decisions with regard to future urban development within the Restricted Development Area. Since property owners and developers are dealt with in this decision process, the Land Use Branch specifically requested that the set-back guidelines be established with reasonable technical basis.

In previous slope movement studies to establish set-back guidelines in urban areas, both theoretical and empirical methods have been applied. As described by Townsend and Thomson (1980) the theoretical method involves the use of computer-aided slope stability analyses to establish a set-back from the valley crest to a theoretical location of a rupture surface that has a Factor of Safety against movement usually greater than 1.3. These analyses have been based on detailed stratigraphic and groundwater pressure conditions obtained from geomorphological mapping a borehole drilling program including the installation of piezometers. This method has been applied on a site specific basis within Edmonton by R.M. Hardy &

Associates Ltd., (1974, 1975a, 1975b). Although it has a sound technical basis, the amount and cost of the field investigations and analyses usually inhibits its application to long reaches of a river valley. In reports by Hardy & Associates (1978) Ltd. (1983, 1984) to establish set-back guidelines over long reaches of a river valley, the slopes were grouped into sectors based on similar stratigraphy and groundwater pressure conditions. This allowed a typical slope profile to be analysed from each sector. The end result of this theoretical method is set-back guidelines which account for valley crest regression from one potential slope movement plus a safety margin added to maintain access when this movement occurs.

The empirical method assesses valley crest regression which has resulted from slope movements within historical times and as explained by Mollard (1981) a new crack can be assumed to develop a distance back from the youngest main scarp approximately equal to the amount of previous valley crest regression. This method has been applied to long reaches of river valley by Mackay and Thomson (1980) and Ruban and Thomson (1983). It is suited for long reaches because it simply involves measuring valley crest regressions that have resulted from active slope movements on a series of airphotos dating as far back as available. The end result is set-back guidelines usually presented as 1 to 2 times the valley depth based on twice the measured regression to provide a safety margin against future slope movements. However, the guidelines established by this method can easily be disputed by landowners and developers as to the probability of when and how much future valley crest regression will occur at their specific site.

The simplification of stratigraphy and groundwater pressure conditions in applying the theoretical method to large areas and the uncertainty involved in applying the empirical method has usually produced the need for a covering final recommendation that the set-back guidelines should be refined on a site specific development basis using theoretical slope stability investigation and analyses. (Mackay and Thomson, 1980; Ruban and Thomson, 1983; Hardy & Associates (1978) Ltd. 1983, 1984).

To satisfy the requirements specified by the Land Use Branch, this study provides a descriptive inventory of the slope movements and establishes set-back guidelines based on the ultimate angle of stability concept. Vallejo and Edil (1979) and Mollard (1981) have explained that, after abandonment, shoreline and river slopes degrade to an inclination at or below which rapid movements do not occur. This inclination has been termed the ultimate angle of stability which has been shown by Vallejo and Edil (1979) to depend on stratigraphy, specifically the residual angle of shearing resistance of the soil and bedrock comprising the slopes, and the groundwater pressure conditions. On the basis of this concept, set-back guidelines can be established as the ultimate angle of stability should always be less than the inclination of those slopes which are undergoing repeated cycles of movement and oversteepening caused by lateral river or creek erosion at their toe.

1.1 Thesis Outline

The geology of the study area is described in Chapter 2. This chapter begins with a review of previous work done in the Edmonton area. The geology of the study area is then described based on mapping of outcrop sections and borehole investigations by the writer and with reference to pertinent information provided in the previous geologic publications and reports.

Chapter 3 describes the hydrogeology of the study area based on the information provided in the available reports, supported by observations made by the writer during the field work.

Chapter 4 begins with a review of previous slope movement studies to provide background information on classification and identification and factors which commonly affect slope stability along river valleys throughout the Prairie Provinces. A descriptive slope movement inventory is provided for the study based on airphoto and field mapping done by the writer, followed by a summary of the stability conditions along the river and tributary creek valleys.

Set-back guidelines are established for the study area in Chapter 5. A review of previous studies provides a description of the methods and concepts used to predict valley crest regression and establish set-back guidelines along river valleys in other urban areas and around reservoir and lake shorelines. This is followed by a description of the method developed by the writer to establish guidelines for the study area and a summary discussion of the resulting data.

Chapter 6 is a summary discussion and presents conclusions regarding the slope movement conditions delineated, and the set-back guidelines established for the study area. The predominant types of slope movements and their mode of occurrence are discussed with an emphasis on the geological and groundwater factors that affect slope stability in the study area. The resulting set-back guidelines are discussed with regard to their application for preliminary land use planning and to other methods used to establish set-backs. In addition potential ways to further refine set-back guidelines are discussed. Lastly, development restrictions which should be imposed when applying the guidelines to future residential and major building developments are outlined.

1.2 Location

The study area is located between the urban areas of Edmonton and Fort Saskatchewan as shown on Figure 1 in Appendix 1. It encompasses the North Saskatchewan River and tributary creek valleys within the Edmonton-Fort Saskatchewan Restricted Development Area and a reach of the river valley through Sec. 19 and 29-53-23-W4 upstream of the Restricted Development Area. In total approximately 20 km of river valley and 8 km of tributary creek valleys are contained within the study area.

1.3 Physiography

1.3.1 Previous Work

The physiography of the study area has been described in previous publications and reports. The physiographic regions of Alberta have been depicted on a map in the Atlas of Alberta (Drinkwater, 1969). In their biophysical report, Strong and McCallum (1984) described the surface topography of the upland plains within the Edmonton-Fort Saskatchewan Restricted Development Area which the study area encompasses.

In the North Saskatchewan River valley which dissects the study area from southwest to northeast, Kathol and McPherson (1975) described five terrace levels in their report on the urban geology of Edmonton. As well, Thomson and Townsend (1979) reported the occurrence of three terrace levels along the river valley, in their study of river erosion rates and bank stabilization in the Edmonton area.

Additional physiographic information such as relief of the upland ground surface and configuration of the North Saskatchewan River valley was provided by the contouring shown on 1:25,000 National Topographic Maps and 1:5000 Cadastral contour maps (Canada Department of Energy, Mines and Resources, 1973; Ecological Land Survey Ltd., 1984).

1.3.2 Topography and Drainage

The study area lies within the Eastern Plains physiographic region of Alberta (Drinkwater 1969). The upland surface has a gently undulating to undulating topography (Strong and MacCullum, 1984). Topographic maps indicate this surface, which has a relief of less than 5 m, slopes gently towards the North Saskatchewan River valley.

From the upstream end to approximately halfway through the study area in Sec. 14-54-23-W4, the North Saskatchewan River meanders around broad terraces in a valley 2 to 3.7 km wide and 27 to 39 m deep (Figure 1; Appendix 1). In the downstream half of the study area the river flows through gentle bends around smaller terraces in a comparatively narrow valley 0.5 to 1.3 km wide and 18 to 39 m deep. These terraces which form the valley bottom occur at 7 to 8 m above river level and correspond to the low level terraces identified in the Edmonton area by Kathol and McPherson (1975) and referred to by Thomson and Townsend (1979). Within the study area the surface of these terraces are characterized by coarse meander scrolls and channel scars. Several of them are being mined for sand and gravel particularly those from N1/2 20-53-23-W4 downstream into the N1/2 13-53-23-W4. With reference to previous work by Westgate, Kalas and Evans (1976), Thomson and Townsend (1979) reported that radiocarbon dates from material in the sand and gravel indicate the low level terraces to be approximately 8,000 years old.

There are five main tributary creeks that enter the North Saskatchewan River valley within the study area (Figure 1; Appendix 1). Those on the northeast side of the river valley include Horsehills Creek and North Creek while on the southwest side there is the Oldman Creek, Point-aux-Pins Creek and Ross Creek. The valleys occupied by these creeks are generally steep sided and V-shaped. With the exception of Ross Creek the depth of the valleys at their mouths ranges from 15 to 30 m while their width varies from 150 to 180 m. Ross Creek occupies a ravine which is up to 10 m deep and 100 m wide near its mouth. In addition to these main creek valleys, there are three smaller unnamed creeks designated T1, T2 and T3. The T1 creek is located in SE27-53-23-W4 approximately 0.5 km southwest of the Oldman Creek. The T2 and T3 creeks are located in NE23 and SW26-54-23-W4 approximately 1.5 km and 0.5 km southwest of North Creek, respectively.

CHAPTER 2

GEOLOGY

2.1 Previous Work

Earlier geological reports and maps which provided information pertinent to the study area, are by Bayrock and Berg (1966) who reported on the geology of Central Edmonton and by Carlson (1967) who interpreted the bedrock surface topography and occurrence of preglacial valleys underlying the Edmonton area. In addition, the surficial geology of the National Topographic System (NTS) map sheet 83H was mapped by Bayrock (1972) while McPherson and Kathol (1972) provided subsurface information in their report consisting of descriptive logs from measured outcrop sections and a detailed drilling program in the Edmonton area. Kathol and McPherson (1975) later produced a comprehensive geological data base with their report on the urban geology of Edmonton. Also, on a regional basis, Green (1972) compiled a bedrock geology map for the Province of Alberta.

Other reports have dealt with more specific aspects or areas of the geology. Thomson (1971) delineated the stratigraphy of the Lesueur Landslide located in the study area, while May and Thomson (1978) reported on the geology and geotechnical properties of the Edmonton area tills. Andriashek and MacMillan (1981) interpreted the geology of the recently annexed areas of Edmonton to supplement the geological data base provided by Kathol and McPherson (1975). Catto (1984) mapped in detail the bedrock and overlying surficial deposits exposed in the excavation for the Convention Centre in Edmonton.

Unpublished reports also contain site specific geological information. R.M. Hardy & Associates Ltd. (1974, 1976) investigated the subsurface conditions for construction projects in the Clareview area of northeast Edmonton while EBA Engineering Consultants Ltd. (1973) performed a slope stability investigation for the Pineview Subdivision in Fort Saskatchewan. In addition, reports by the City of Edmonton Materials Testing Division (1970, 1978) and Underwood McLellan Limited (1978, 1980) presented the results of subsurface investigations for gravel exploration and construction projects in the low level terraces along the North Saskatchewan River valley in the study area.

The information contained in these previous reports provided a description of the occurrence and sequence of bedrock strata and overburden soils in the Edmonton area. This was used by the writer as a guide in field mapping the geology exposed along the North Saskatchewan River valley slopes through the study area.

2.2 Field Work

As part of the field work performed by the writer from August to October 1983, outcrop sections on the river valley slopes were described and measured in conjunction with inspecting and mapping the slope movements in the study area. This stratigraphy is shown on profiles of the associated slope movements as Figures 18, 26, 28, 49, 64, and 77 in Sections 4.3.1 to 4.3.6 of Chapter 4. A legend of the stratigraphic symbols used in these profiles is given in Figure 15 in Section 4.2.

Three boreholes designated BH-A2, BH-B1 and BH-C1 were drilled in December, 1983 and January, 1984 to complete the subsurface stratigraphy where outcrop sections were partly covered by displaced material. Borehole locations are shown on Figure 1 in Appendix 1. The boreholes were drilled with Alberta Environment's Mobile B61 drill rig to depths of 27 to 35 m ending in bedrock at or below river level. Drilling through overburden soils was accomplished with a 203 mm diameter hollow stem auger. Undisturbed samples of clayey soils were taken with a 76 mm diameter Shelby Tube while disturbed samples of sandy soils were taken in conjunction with a Standard Penetration Test (SPT). Sampling intervals ranged from continuous in soils of interest to 1.5 m in uniform deposits. Below the overburden, bedrock was cored to the end of the borehole with either a CB19-A or NXW barrel. The subsurface stratigraphy encountered and associated laboratory testing results are presented on borehole logs as Figures 2 to 4. A list of the word abbreviations used in the descriptions on the logs is given in Table 1.

2.3 Geological Setting

Green (1972) has depicted Upper Cretaceous sandstone, shale and siltstone strata as underlying the study area. Kathol and McPherson (1975) described these strata as poorly indurated, often bentonitic and

Table 1 - Borehole Log Word Abbreviations

alluv	alluvial
AP	auger hole (power)
app	appearance
BR	bedrock
BTE	bentonite
bent'c	bentonitic
blk	black
blky	blocky
B	borrow
br	brown
cal	calcareous
carb	carbonaceous
ch'ge	change
c	coarse
cl'y	clayey
cons	consistency
crum	crumbled
diag	diagonal
dil	dilatent
Dol	dolomite
dk	dark
f	fine
fis	fissile
frag	fragmented or fragment
frac	fractured
fria	friable
g	grain or grained
G	gravel
grvly	gravelly
grn	green
gry	grey
gyp	gypsum
hghly or H	highly
horz	horizontal
i	intermediate
incl	inclusions
int'd	interbedded
jtd	jointed
lam	laminated
LS	limestone
lt	light
med	medium
mod	moderately
mtld	mottled
MS	siltstone
non-cal	non-calcerous
occ	occasional
org	organic
pkts	pockets
pt	peat
rem	remolded
rec	recovery
rty	rusty
sdy	sandy
sh	shale
slicks	slickensides
sl'ty	slightly
strat	stratified
struct	structure
SS	sandstone
tex	texture
tr	trace
V	very
weath	weathered
whte	white
yel	yellow

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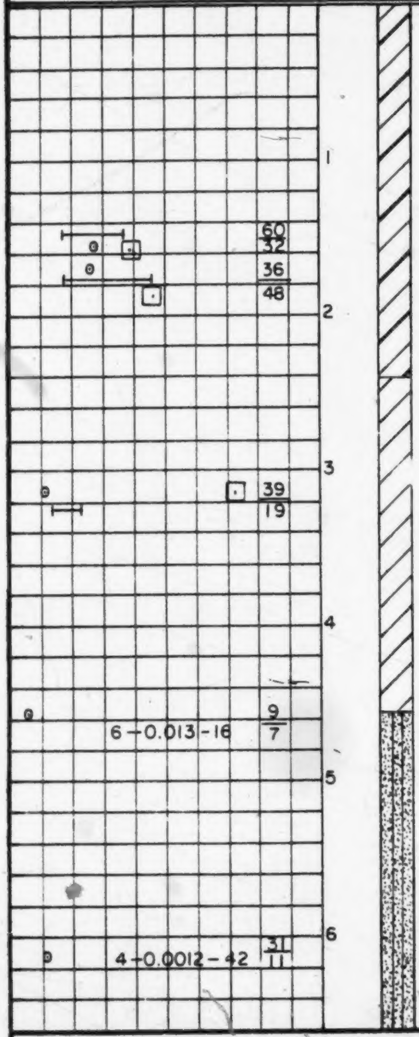
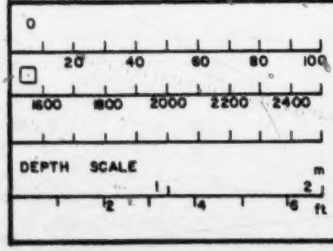
DESIGN AND CONSTRUCTION DIVISION
GEOTECHNICAL BRANCH
MATERIALS TESTING LABORATORY

PROJECT NORTH SASKATCHEWAN RIVER SLOPE STUDY
SITE Slope Movement Area A
HOLE No. BH- A2 ELEV. 621.72 m
LOCATION As shown on Figure 1
TECHNOLOGIST A.S., J.B. DATE DRILLED July, 1984

BOREHOLE AND TEST LOG


TEST RESULTS
DEPTH (m)
SYMBOL
1
60/32
36/48
2
3
39/19
4
6-0.013-16
9/7
5
6
4-0.0012-42
31/11

DEPTH (m)	DESCRIPTION	SAMPLE	OTHER INFORMATION
			Drilled with a Mobile B-61, 203mm HCA
1.5	CI-stiff-v stiff, mtld lt & med br, rootlets.	◿	P P 144 Rec 0.25m/0.30m=83%
3.1	CL(TILL)-hard, lt to med br, rust stained, pebbles to 10mm, coal chips, gypsum.	◿	P P 383+ Rec 0.15m/0.25m=60%
4.6	SM-brownish yel, f-med rust stained, pebbles to 10mm.	◿	Rec 0.10m/0.20m=50%
6.1	as above, f g,	◿	Rec 0.10m/0.10m=100%


0
20
40
60
80
100
1600
1800
2000
2200
2400
DEPTH SCALE
m
1
2
2
4
6
ft

☐ TOPSOIL OR NO SAMPLE
▨ GRAVEL
▨ SAND OR SANDSTONE
▨ CLAY OR SHALE
▥ SILT OR SILTSTONE
◿ UNDISTURBED SAMPLE
☒ DISTURBED SAMPLE

ʘ-MOISTURE CONTENT (%), ⊡-WET UNIT WEIGHT (kg/m^3), K-PERMEABILITY (cm/s), F.A-FLIGHT AUGER, HCA-HOLLOW CORE AUGER, ∇ OR S.P.T.- STANDARD PENETRATION TEST BLOW COUNT, PP-POCKET PENETROMETER (kN/m^2), ● OR Qu-UNCONFINED COMPRESSION (kN/m^2), W_p-PLASTIC LIMIT (%) ⊢—⊣ W_L-LIQUID LIMIT (%), ----- CORE RECOVERY (%), 12-0.03-22 -12=% RETAINED ON No.4 SIEVE, 0.03=D_{10} SIZE mm, 22=% No. 200 SIEVE, $\frac{40}{35} = \frac{\%\ SILT}{\%\ CLAY}$, $\underline{\nabla}$- WATER LEVEL NOT TAKEN.

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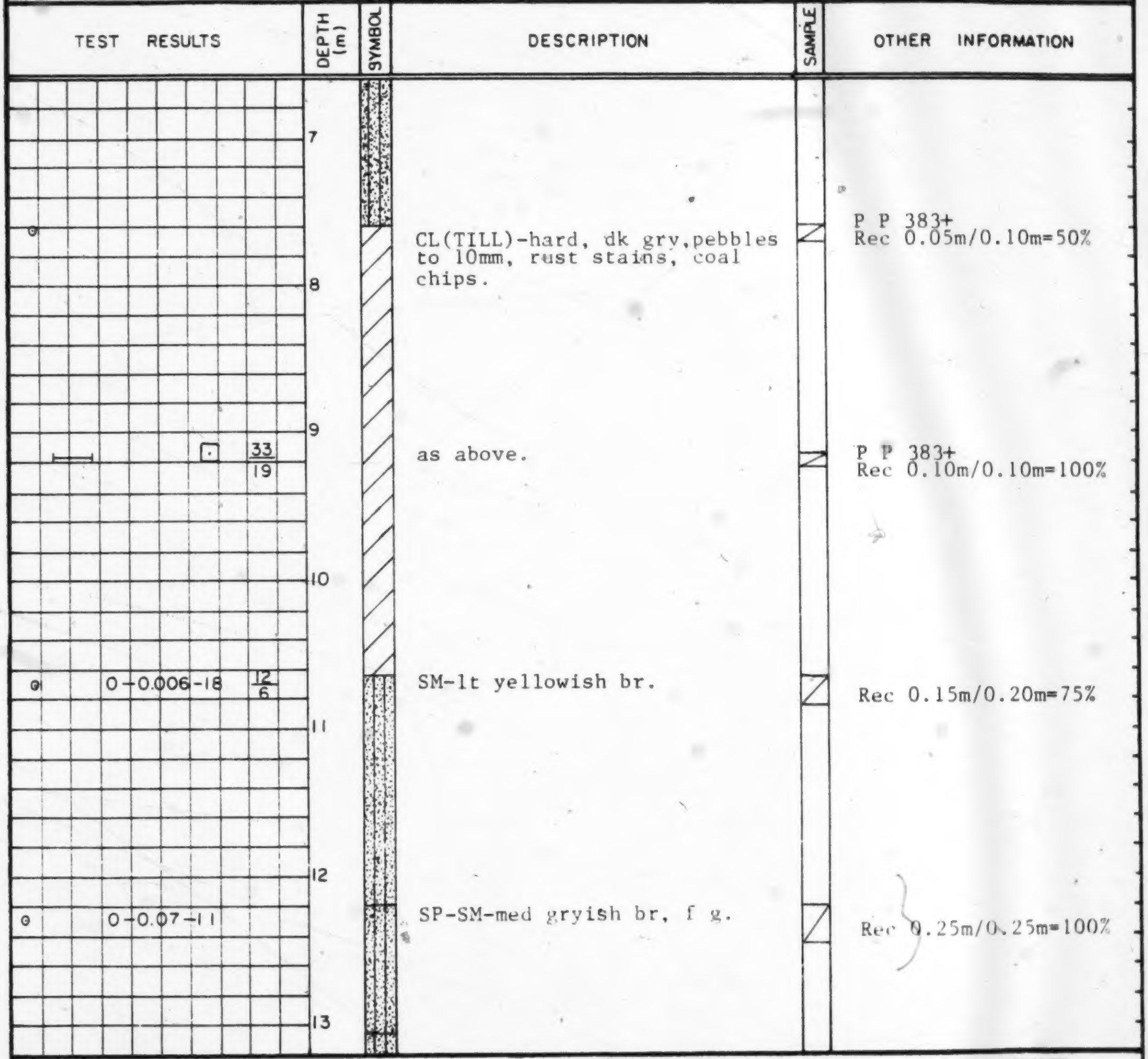
MATERIALS TESTING LABORATORY

PROJECT	NORTH SASKATCHEWAN RIVER SLOPE STUDY
SITE	Slope Movement Area A
HOLE No.	BH-A2
ELEV.	621.72 m
LOCATION	As shown on Figure 1
TECHNOLOGIST	A.S., J.B.
DATE DRILLED	July, 1984

BOREHOLE AND TEST LOG



TEST RESULTS	DEPTH (m)	DESCRIPTION	OTHER INFORMATION
⊙	7.7	CL(TILL)-hard, dk gry, pebbles to 10mm, rust stains, coal chips.	P P 383+ Rec 0.05m/0.10m=50%
⊢—⊣ ⊡ $\frac{33}{19}$	9.2	as above.	P P 383+ Rec 0.10m/0.10m=100%
⊙ 0-0.006-18 $\frac{12}{6}$	10.7	SM-lt yellowish br.	Rec 0.15m/0.20m=75%
⊙ 0-0.07-11	12.3	SP-SM-med gryish br, f g.	Rec 0.25m/0.25m=100%

0
20 40 60 80 100
⊡
1600 1800 2000 2200 2400

DEPTH SCALE m 1 2
ft 2 4 6

▭	▨	⠿	▨	▥	◸	☒
TOPSOIL OR NO SAMPLE	GRAVEL	SAND OR SANDSTONE	CLAY OR SHALE	SILT OR SILTSTONE	UNDISTURBED SAMPLE	DISTURBED SAMPLE

⊙-MOISTURE CONTENT (%), ⊡-WET UNIT WEIGHT (kg/m³), K-PERMEABILITY (cm/s), F.A-FLIGHT AUGER, HCA-HOLLOW CORE AUGER, ∇ OR S.P.T.- STANDARD PENETRATION TEST BLOW COUNT, PP-POCKET PENETROMETER (kN/m²), ● OR Qu-UNCONFINED COMPRESSION (kN/m²), W_p- PLASTIC LIMIT (%) ⊢——⊣ W_L- LIQUID LIMIT (%), - - - - - CORE RECOVERY (%), 12-0.03-22 -12=% RETAINED ON No.4 SIEVE, 0.03=D_{10} SIZE mm, 22=% No.200 SIEVE, $\frac{40}{35} = \frac{\%\ SILT}{\%\ CLAY}$, ∇̲ - WATER LEVEL

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MATERIALS TESTING LABORATORY

PROJECT NORTH SASKATCHEWAN RIVER SLOPE STUDY
SITE Slope Movement Area A
HOLE No. BH-A2 ELEV. 621.72 m
LOCATION As shown on Figure 1
TECHNOLOGIST A.S., J.B. DATE DRILLED July, 1984

BOREHOLE AND TEST LOG

TEST RESULTS	DEPTH (m)	SYMBOL	DESCRIPTION	SAMPLE	OTHER INFORMATION
θ 0-(—)-15			SM-lt gry, f g.	⧄	Rec 0.25m/0.25m=100%
	14				
	15				
θ 0-(—)-23			as above, yellowish br.	☒	SPT = 54 for 152mm
	16				
θ 0-(—)-13	17		as above, lt br, coal spots.	☒	SPT = 78
	18				
θ 0-(—)-18			as above, med gryish br, f-med.	☒	SPT = 75
	19				

θ 0 20 40 60 80 100
⊡ 1600 1800 2000 2200 2400
DEPTH SCALE m 1 2
ft 2 4 6

☐ TOPSOIL OR NO SAMPLE
GRAVEL
SAND OR SANDSTONE
▨ CLAY OR SHALE
▥ SILT OR SILTSTONE
⧄ UNDISTURBED SAMPLE
☒ DISTURBED SAMPLE

θ—MOISTURE CONTENT (%), ⊡—WET UNIT WEIGHT (kg/m^3), K—PERMEABILITY (cm/s), F.A—FLIGHT AUGER, HCA—HOLLOW CORE AUGER, ∇ OR S.P.T.—STANDARD PENETRATION TEST BLOW COUNT, PP—POCKET PENETROMETER (kN/m^2), ● OR Qu—UNCONFINED COMPRESSION (kN/m^2), W_p—PLASTIC LIMIT (%) ├──┤ W_L—LIQUID LIMIT (%), ------ CORE RECOVERY (%), 12—0.03—22 —12 = % RETAINED ON No.4 SIEVE, 0.03 = D_{10} SIZE mm, 22 = % No. 200 SIEVE, $\frac{40}{35} = \frac{\%\ SILT}{\%\ CLAY}$, ⊽—WATER LEVEL

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Figure 2 Sheet 4 of 5

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PROJECT NORTH SASKATCHEWAN RIVER SLOPE STUDY
SITE Slope Movement Area A
HOLE No. BH-A2 ELEV. 621.72 m
LOCATION As shown on Figure 1
TECHNOLOGIST A.S., J.B. DATE DRILLED July, 1984

BOREHOLE AND TEST LOG

TEST RESULTS	DEPTH (m)	SYMBOL	DESCRIPTION	SAMPLE	OTHER INFORMATION
⊙ 0-0.084-9	20	⁘	SP-SM-lt gryish br, f-med g.	☒	SPT = 87
	21	⁘			
⊙ 3-0.10-7		⁘	as above, gry, pebbles to 10mm.	☒	SPT = 109
	22	⁘			
⊙ 29-0.12-7	23	⁘	as above, f-c g, grvly to 20mm.	☒	SPT = 90 for 127mm
	24	⁘			
	25	⁘			
⊙ 0-(—)-40 ⊢—⊣ 20/20	26	⁘	SANDSTONE-lt to med gry, f g, bent'c.	☒	SPT = 154

⊙ 0 20 40 60 80 100
⊡ 1600 1800 2000 2200 2400

DEPTH SCALE
m 1 2
ft 2 4 6

☐	▦	⁘	▨	▥	⧄	☒
TOPSOIL OR NO SAMPLE	GRAVEL	SAND OR SANDSTONE	CLAY OR SHALE	SILT OR SILTSTONE	UNDISTURBED SAMPLE	DISTURBED SAMPLE

⊙– MOISTURE CONTENT (%), ⊡– WET UNIT WEIGHT (kg/m³), K– PERMEABILITY (cm/s), F.A.– FLIGHT AUGER, HCA– HOLLOW CORE AUGER, ∇ OR S.P.T.– STANDARD PENETRATION TEST BLOW COUNT, PP– POCKET PENETROMETER (kN/m²), ● OR Qu– UNCONFINED COMPRESSION (kN/m²), W_p– PLASTIC LIMIT (%) ⊢——⊣ W_L– LIQUID LIMIT (%), - - - - - CORE RECOVERY (%), 12–0.03–22 –12 = % RETAINED ON No. 4 SIEVE, 0.03 = D_{10} SIZE mm, 22 = % No. 200 SIEVE, $\frac{40}{35} = \frac{\%\ SILT}{\%\ CLAY}$, ∇– WATER LEVEL

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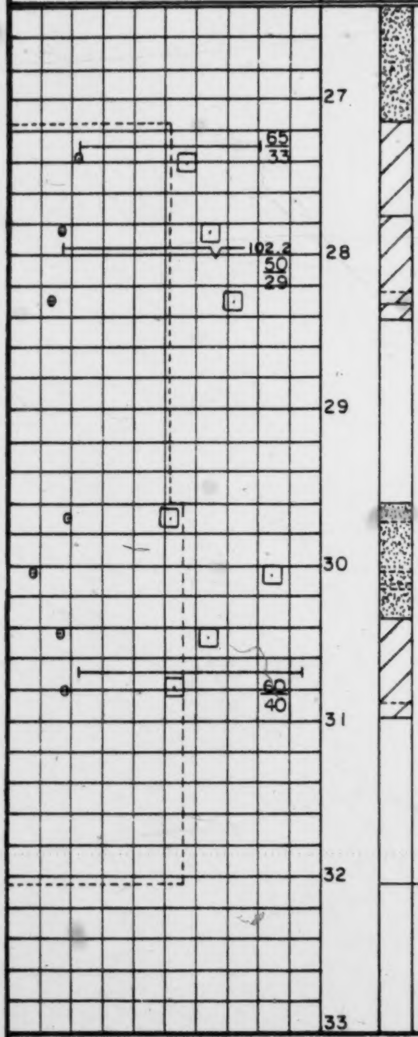
MATERIALS TESTING LABORATORY

PROJECT NORTH SASKATCHEWAN RIVER SLOPE STUDY
SITE Slope Movement Area A
HOLE No. BH-A2 ELEV. 621.72 m
LOCATION As shown on Figure 1
TECHNOLOGIST A.S., J.B. DATE DRILLED July, 1984

BOREHOLE AND TEST LOG

TEST RESULTS | DEPTH (m) | SYMBOL | DESCRIPTION | SAMPLE | OTHER INFORMATION



DESCRIPTION	OTHER INFORMATION
SHALE-cl'y, med blue gry, oxidized olive, badly frac, hard.	Began coring with NXW barrel.
SHALE-sdy-bent'c, hard-v hard, lt gry, badly frac, carb @ 1100-1180mm.	
SHALE-cl'y, v hard, med gry, badly frac.	
SANDSTONE-v hard, lt gry, badly to mod frac, carb @ 130-430mm, coal layers to 2mm @ 510-560mm.	
SHALE-cl'y, hard-v hard, med dk gry, badly frac, silty sh layers @ 1270-1380.	
END OF HOLE	

0 20 40 60 80 100
⊡ 1600 1800 2000 2200 2400

DEPTH SCALE
m: 1 2
ft: 2 4 6

☐ TOPSOIL OR NO SAMPLE
▨ GRAVEL
▨ SAND OR SANDSTONE
▨ CLAY OR SHALE
▥ SILT OR SILTSTONE
◪ UNDISTURBED SAMPLE
☒ DISTURBED SAMPLE

ʘ-MOISTURE CONTENT (%), ⊡-WET UNIT WEIGHT (kg/m³), K-PERMEABILITY (cm/s), F.A-FLIGHT AUGER, HCA-HOLLOW CORE AUGER, ∇ OR S.P.T.- STANDARD PENETRATION TEST BLOW COUNT, PP-POCKET PENETROMETER (kN/m²), ● OR Qu-UNCONFINED COMPRESSION (kN/m²), W_p-PLASTIC LIMIT (%) ⊢—⊣ W_L-LIQUID LIMIT (%), ------ CORE RECOVERY (%), 12-0.03-22 -12= % RETAINED ON No.4 SIEVE, 0.03= D_{10} SIZE mm, 22= % No. 200 SIEVE, $\frac{40}{35} = \frac{\%\ SILT}{\%\ CLAY}$, $\underline{\nabla}$- WATER LEVEL

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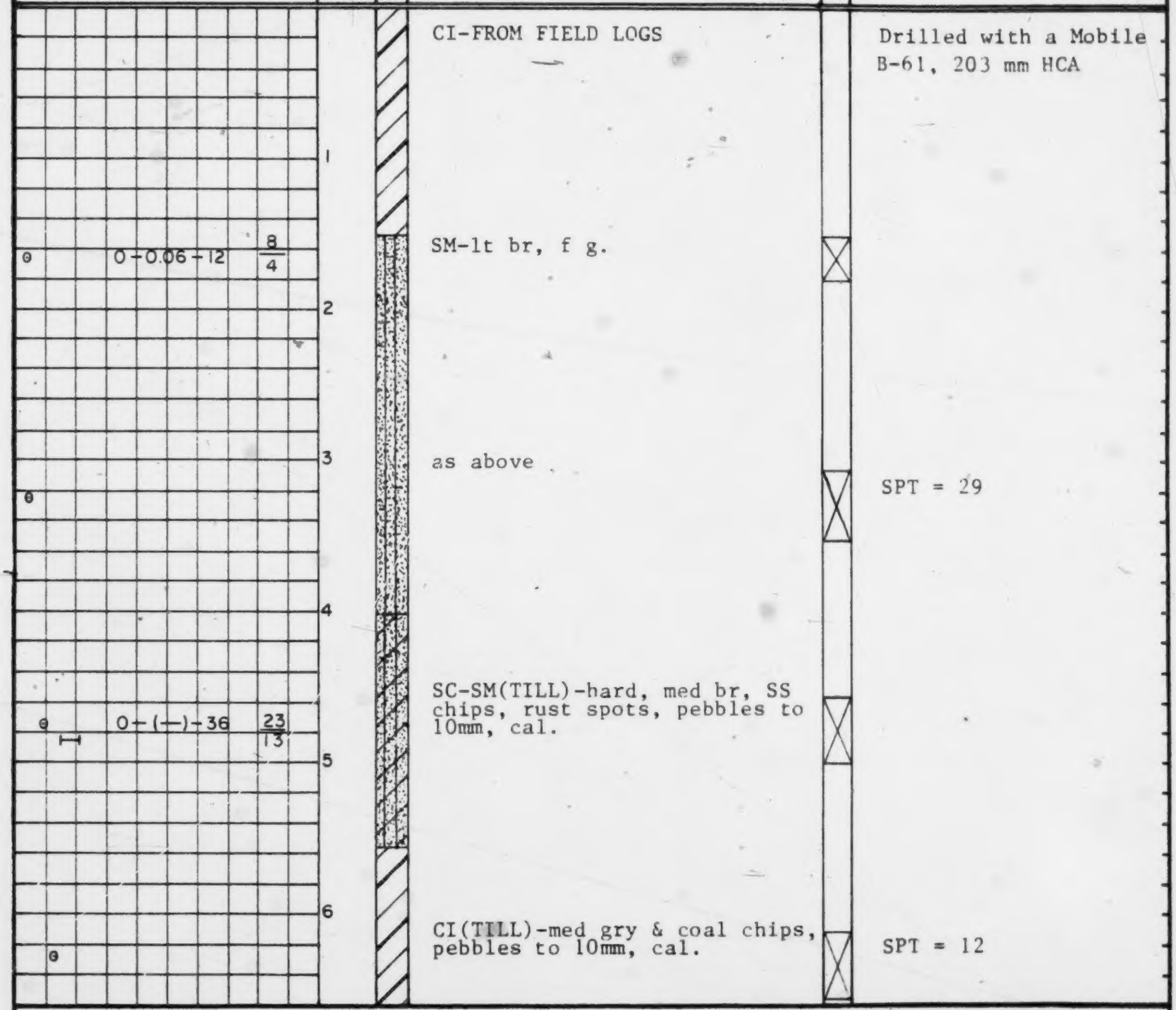
PROJECT: NORTH SASKATCHEWAN RIVER SLOPE STUDY
SITE: Slope Movement Area B
HOLE No.: BH-B1 ELEV.: 621.80 m
LOCATION: As shown on Figure 1
TECHNOLOGIST: A.S., M.E. DATE DRILLED: July, 1984

BOREHOLE AND TEST LOG



TEST RESULTS	DEPTH (m)	SYMBOL	DESCRIPTION	SAMPLE	OTHER INFORMATION
		▨	CI-FROM FIELD LOGS		Drilled with a Mobile B-61, 203 mm HCA
	1	▨			
θ 0-0.06-12 $\frac{8}{4}$		░	SM-lt br, f g.	☒	
	2	░			
	3	░	as above		
θ		░		☒	SPT = 29
	4	░▨			
θ ⊢⊣ 0-(—)-36 $\frac{23}{13}$		░▨	SC-SM(TILL)-hard, med br, SS chips, rust spots, pebbles to 10mm, cal.	☒	
	5	░▨			
	6	▨			
θ		▨	CI(TILL)-med gry & coal chips, pebbles to 10mm, cal.	☒	SPT = 12

0 — 20 — 40 — 60 — 80 — 100
⊡ 1600 — 1800 — 2000 — 2200 — 2400

DEPTH SCALE: 1, 2 m; 2, 4, 6 ft

☐	▦	░	▨	▥	◩	☒
TOPSOIL OR NO SAMPLE	GRAVEL	SAND OR SANDSTONE	CLAY OR SHALE	SILT OR SILTSTONE	UNDISTURBED SAMPLE	DISTURBED SAMPLE

θ—MOISTURE CONTENT (%), ⊡—WET UNIT WEIGHT (kg/m^3), K—PERMEABILITY (cm/s), FA—FLIGHT AUGER, HCA—HOLLOW CORE AUGER, ∇ OR S.P.T.—STANDARD PENETRATION TEST BLOW COUNT, PP—POCKET PENETROMETER (kN/m^2), ● OR Qu—UNCONFINED COMPRESSION (kN/m^2), W_p—PLASTIC LIMIT (%) ⊢⊣ W_L—LIQUID LIMIT (%), - - - - - CORE RECOVERY (%), 12—0.03—22 —12 = % RETAINED ON No. 4 SIEVE, 0.03 = D_{10} SIZE mm, 22 = % No. 200 SIEVE, $\frac{40}{35} = \frac{\%\ SILT}{\%\ CLAY}$, ∇—WATER LEVEL NOT TAKEN.

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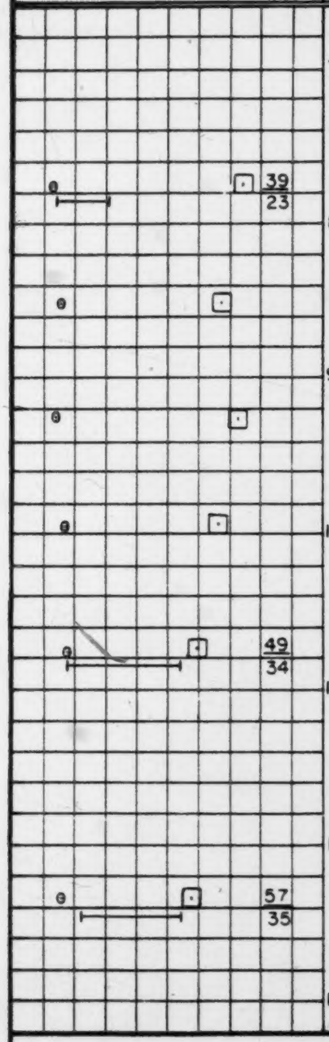
GEOTECHNICAL BRANCH
MATERIALS TESTING LABORATORY

PROJECT NORTH SASKATCHEWAN RIVER SLOPE STUDY
SITE Slope Movement Area B
HOLE No. BH-B1 ELEV. 621.80 m
LOCATION As shown on Figure 1
TECHNOLOGIST ~~A.S.~~, M.E. DATE DRILLED July, 1984

BOREHOLE AND TEST LOG



DEPTH (m)	SYMBOL	DESCRIPTION	SAMPLE	OTHER INFORMATION
7	▨			
	▨	as above, hard, rust coated fissures.	⧄	P P 383+ Rec 0.30m/0.30m=100%
8	▨			
	▨	as above, hard, silt pkts.	⧄	P P 383+ Rec 0.30m/0.30m=100%
9	▨			
	▨	as above, hard, silt pkts.	⧄	P P 383+ Rec 0.20m/0.30m=67%
10	▨	as above, hard.	⧄	P P 383+ Rec 0.20m/0.30m=67%
	▨	SHALE-cl'y, hard, mtld lt & med gry, reworked with SS, rust stains.	⧄	P P 383+ Rec 0.35m/0.40m=86%
11	▨			
12	▨			
	▨	as above, hard, lt olive gry, rust stains.	⧄	P P 383+ Rec 0.30m/0.30m=100%
13	▨			

θ 0 20 40 60 80 100
⊡ 1600 1800 2000 2200 2400

DEPTH SCALE m 1 2
ft 2 4 6

☐ TOPSOIL OR NO SAMPLE
GRAVEL
SAND OR SANDSTONE
▨ CLAY OR SHALE
SILT OR SILTSTONE
⧄ UNDISTURBED SAMPLE
☒ DISTURBED SAMPLE

θ-MOISTURE CONTENT (%), ⊡-WET UNIT WEIGHT (kg/m^3), K-PERMEABILITY (cm/s), F.A-FLIGHT AUGER, HCA-HOLLOW CORE AUGER, ∇ OR S.P.T.-STANDARD PENETRATION TEST BLOW COUNT, PP-POCKET PENETROMETER (kN/m^2), ● OR Qu-UNCONFINED COMPRESSION (kN/m^2), W_p-PLASTIC LIMIT (%) ├──┤ W_L-LIQUID LIMIT (%), ------ CORE RECOVERY (%), 12-0.03-22 -12=% RETAINED ON No.4 SIEVE, 0.03=D_{10} SIZE mm, 22=% No. 200 SIEVE, $\frac{40}{35}$ = $\frac{\%\ SILT}{\%\ CLAY}$, ∇- WATER LEVEL

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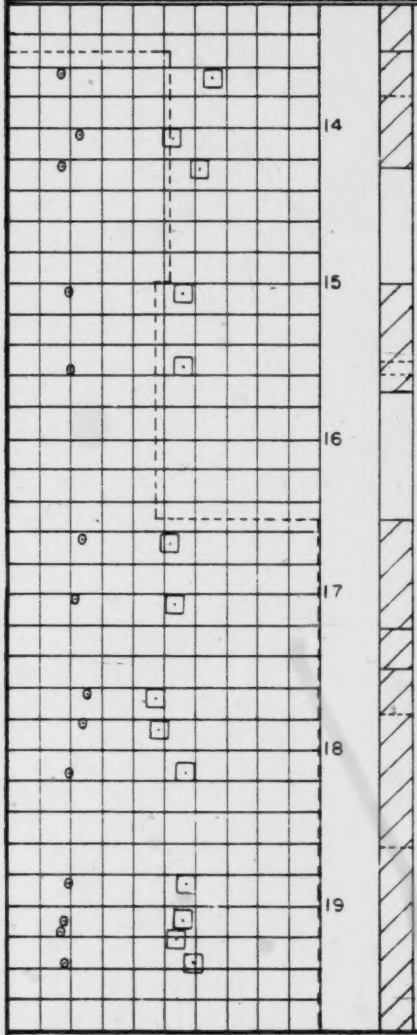
Alberta ENVIRONMENT

DESIGN AND CONSTRUCTION DIVISION
GEOTECHNICAL BRANCH
MATERIALS TESTING LABORATORY

PROJECT NORTH SASKATCHEWAN RIVER SLOPE STUDY
SITE Slope Movement Area B
HOLE No. BH-B1 ELEV. 621.80 m
LOCATION As shown on Figure 1
TECHNOLOGIST A.S., M.E. DATE DRILLED July, 1984

BOREHOLE AND TEST LOG

TEST RESULTS	DEPTH (m)	SYMBOL	DESCRIPTION	SAMPLE	OTHER INFORMATION



SHALE-cl'y, hard-v hard, med to dk gry to 300, med olive gry from 300-760mm, badly to mod frac.

as above, med olive gry to 510mm, med gry from 510 to 700mm, coal steaks @ 600mm, slicks from 510mm.

SHALE-cl'y, hard-v hard, med olive gry to 120mm, med gry to 710, badly frac to intact.

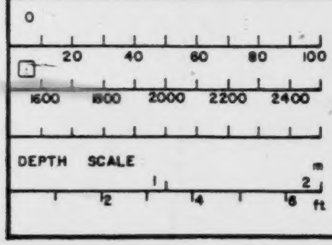
SHALE-silty, hard-v hard, med olive gry, mod frac to intact.

SHALE-cl'y, hard-v hard, med olive gry to 1280, med gry from 1280mm, coal streaks from 1280, badly to mod frac.

as above, hard-v hard, med gry to 610, med olive gry from 610 mm, badly frac to intact.

as above, hard-v hard, med olive gry, badly to mod frac, slicks, infilled fracs.

Began coring with a CB19-A barrel.


0
20
40
60
80
100
1600
1800
2000
2200
2400
DEPTH SCALE
m
1
2
2
4
6
ft

TOPSOIL OR NO SAMPLE
GRAVEL
SAND OR SANDSTONE
CLAY OR SHALE
SILT OR SILTSTONE
UNDISTURBED SAMPLE
DISTURBED SAMPLE

ʘ-MOISTURE CONTENT (%), ⊡-WET UNIT WEIGHT (kg/m^3), K-PERMEABILITY (cm/s), FA-FLIGHT AUGER, HCA-HOLLOW CORE AUGER, ∇ OR S.P.T.-STANDARD PENETRATION TEST BLOW COUNT, PP-POCKET PENETROMETER (kN/m^2), ● OR Qu-UNCONFINED COMPRESSION (kN/m^2), W_p-PLASTIC LIMIT (%) ⊢⊣ W_L-LIQUID LIMIT (%), - - - - - CORE RECOVERY (%), 12-0.03-22 -12=% RETAINED ON No.4 SIEVE, 0.03=D_{10} SIZE mm, 22=% No.200 SIEVE, $\frac{40}{35} = \frac{\%\ SILT}{\%\ CLAY}$, ∇̲-WATER LEVEL

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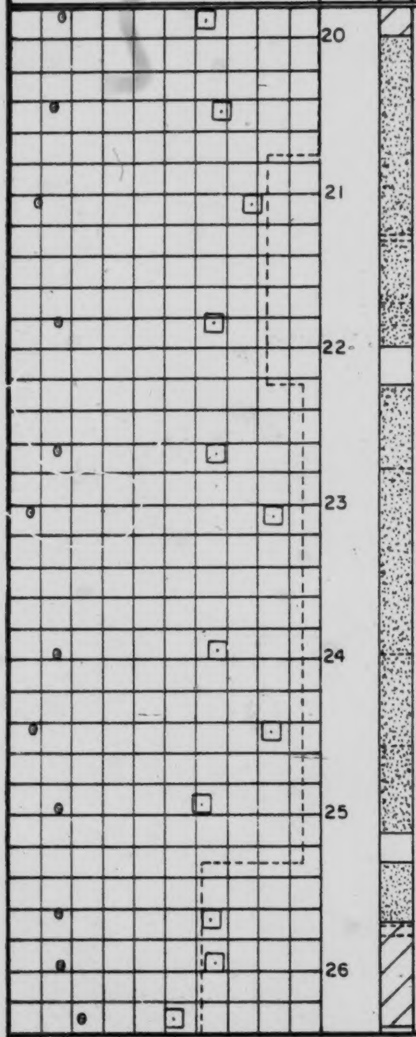
MATERIALS TESTING LABORATORY

PROJECT NORTH SASKATCHEWAN RIVER SLOPE STUDY
SITE Slope Movement Area B
HOLE No. BH-31 ELEV. 621.80 m
LOCATION As shown on Figure 1
TECHNOLOGIST A.S., M.E. DATE DRILLED July, 1984

BOREHOLE AND TEST LOG

TEST RESULTS	DEPTH (m)	SYMBOL	DESCRIPTION	SAMPLE	OTHER INFORMATION



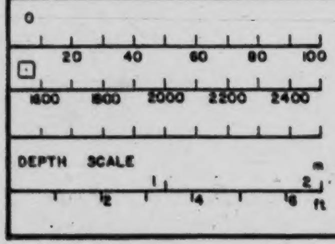
SANDSTONE-hard-v hard, lt gry, mod frac to intact, f g.

as above, bent'c nodules coal lam @ 520-560 & 960-1110mm, coarser g with depth.

as above, coarser g with depth, badly frac to intact clay sh layer to 30mm from 540-1730mm & 2300-2870, bent'c nodules @ 1730-2300mm.

as above, intact, coal lens.

SHALE-cl'y,hard-v hard,dk gry to 870mm, med olive gry from 890mm, badly to mod frac, SS lens @ 410-480mm.



☐ TOPSOIL OR NO SAMPLE
▩ GRAVEL
▒ SAND OR SANDSTONE
▨ CLAY OR SHALE
▥ SILT OR SILTSTONE
◪ UNDISTURBED SAMPLE
☒ DISTURBED SAMPLE

θ-MOISTURE CONTENT (%), ⊡-WET UNIT WEIGHT (kg/m³), K-PERMEABILITY (cm/s), F.A-FLIGHT AUGER, HCA-HOLLOW CORE AUGER, ∇ OR S.P.T.- STANDARD PENETRATION TEST BLOW COUNT, PP-POCKET PENETROMETER (kN/m²), ● OR Qu-UNCONFINED COMPRESSION (kN/m²), W_p-PLASTIC LIMIT (%) ├──┤ W_L-LIQUID LIMIT (%), ------ CORE RECOVERY (%), 12-0.03-22 -12=% RETAINED ON No.4 SIEVE, 0.03=D_{10} SIZE mm, 22=% No.200 SIEVE, $\frac{40}{35} = \frac{\%\ SILT}{\%\ CLAY}$, ∇- WATER LEVEL

MATTE 1074M

Alberta ENVIRONMENT
DESIGN AND CONSTRUCTION DIVISION
GEOTECHNICAL BRANCH
MATERIALS TESTING LABORATORY

PROJECT NORTH SASKATCHEWAN RIVER SLOPE STUDY
SITE Slope Movement Area B
HOLE No. BH-B1 ELEV. 621.80 m
LOCATION As shown on Figure 1
TECHNOLOGIST A.S., M.E. DATE DRILLED July, 1984

BOREHOLE AND TEST LOG

TEST RESULTS	DEPTH (m)	SYMBOL	DESCRIPTION	SAMPLE	OTHER INFORMATION
				◺	
	27		END OF HOLE		
	28				
	29				
	30				
	31				
	32				
	33				

0
20 40 60 80 100
⊡
1600 1800 2000 2200 2400

DEPTH SCALE
m 1 2
ft 2 4 6

☐	⁘	⁙	▨	▥	◺	☒
TOPSOIL OR NO SAMPLE	GRAVEL	SAND OR SANDSTONE	CLAY OR SHALE	SILT OR SILTSTONE	UNDISTURBED SAMPLE	DISTURBED SAMPLE

⊖ - MOISTURE CONTENT (%), ⊡ - WET UNIT WEIGHT (kg/m^3), K - PERMEABILITY (cm/s), F.A - FLIGHT AUGER, HCA - HOLLOW CORE AUGER, ∇ OR S.P.T. - STANDARD PENETRATION TEST BLOW COUNT, PP - POCKET PENETROMETER (kN/m^2), ● OR Qu - UNCONFINED COMPRESSION (kN/m^2), W_p - PLASTIC LIMIT (%) ├──┤ W_L - LIQUID LIMIT (%), - - - - - CORE RECOVERY (%), 12-0.03-22 - 12 = % RETAINED ON No. 4 SIEVE, 0.03 = D_{10} SIZE mm, 22 = % No. 200 SIEVE, $\frac{40}{35} = \frac{\%\ SILT}{\%\ CLAY}$, $\underline{\nabla}$ - WATER LEVEL

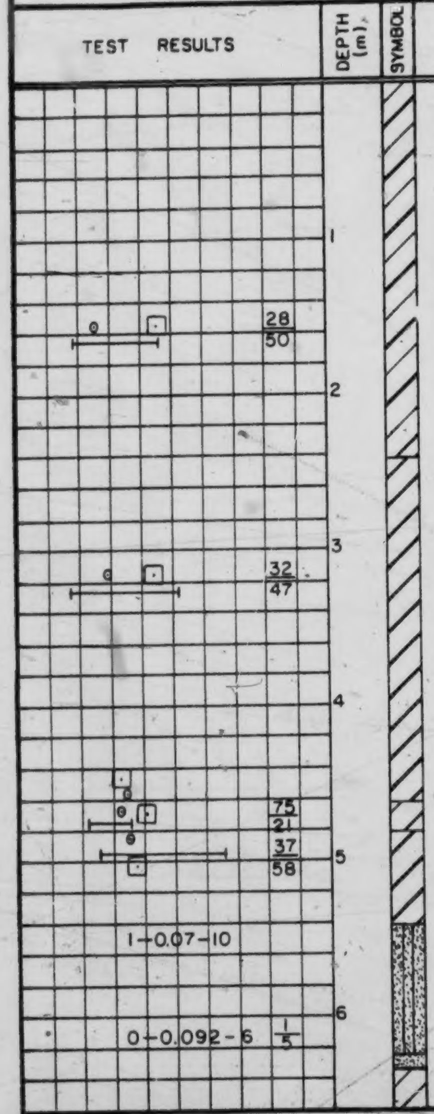
MATTE 1074M

Alberta ENVIRONMENT

DESIGN AND CONSTRUCTION DIVISION
GEOTECHNICAL BRANCH
MATERIALS TESTING LABORATORY

PROJECT: NORTH SASKATCHEWAN RIVER SLOPE STUDY
SITE: Slope Movement Area C
HOLE No.: BH-C1 ELEV.: 639.71 m
LOCATION: As shown on Figure 1
TECHNOLOGIST: A.S., J.B. DATE DRILLED: July, 1984

BOREHOLE AND TEST LOG



TEST RESULTS	DEPTH (m)	DESCRIPTION	OTHER INFORMATION
			Drilled with a Mobile B-61, 203mm HCA
28/50		CI-v stiff, br, odd pebble to 10mm, gyp coal spots, sl'ty cal.	P P 360 Rec 0.25m/0.30m=82%
32/47	3	CH(TILL)-v stiff, med br, coal spots, pebbles to 10mm, mtld, gyp.	P P 287 Rec 0.20m/0.25m=80%
75/21 37/58		as above, stiff-v stiff, CH lens slicks. CI-v stiff, lt br, coal spots, sand parting @ 275mm. CH-v stiff, lt br, mtld, slicks.	P P 192 Rec 0.35m/0.40m=88% P P 249
1-0.07-10		as above. SP-SM-lt br, f g.	Rec 0.15m/0.20m=75%
0-0.092-6 1/5	6	as above.	Rec 0.05m/0.20m/25%
		SHALE-cl'y, dk gry to 175mm, possible bent'c from 175mm,	SPT = 37 Rec 0.25m/0.30m=83%

0 — 20 40 60 80 100
⊡ — 1600 1800 2000 2200 2400
DEPTH SCALE m 1 2 — ft 2 4 6

☐	▩	⁘	▨	▥	◸	☒
TOPSOIL OR NO SAMPLE	GRAVEL	SAND OR SANDSTONE	CLAY OR SHALE	SILT OR SILTSTONE	UNDISTURBED SAMPLE	DISTURBED SAMPLE

⊖-MOISTURE CONTENT (%), ⊡-WET UNIT WEIGHT (kg/m³), K-PERMEABILITY (cm/s), F.A-FLIGHT AUGER, HCA-HOLLOW CORE AUGER, ∇ OR S.P.T.- STANDARD PENETRATION TEST BLOW COUNT, PP-POCKET PENETROMETER (kN/m²), ● OR Qu-UNCONFINED COMPRESSION (kN/m²), W_p-PLASTIC LIMIT (%) ├──┤ W_L-LIQUID LIMIT (%), ------ CORE RECOVERY (%), 12-0.03-22 -12= % RETAINED ON No.4 SIEVE, 0.03= D_{10} SIZE mm, 22= % No.200 SIEVE, $\frac{40}{35} = \frac{\%\ SILT}{\%\ CLAY}$, ∇̲- WATER LEVEL NOT TAKEN.

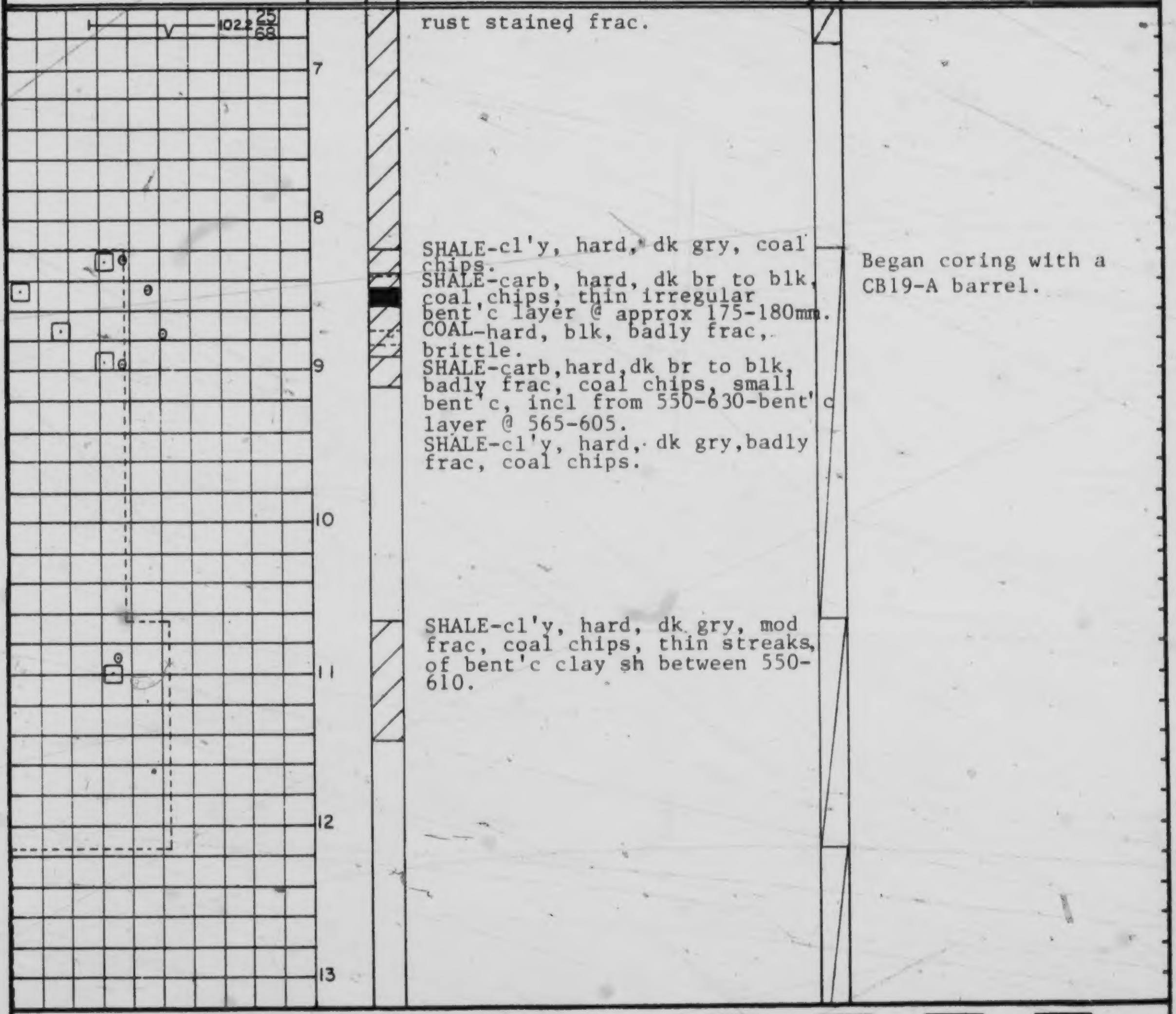
MATTE 1074M

Alberta
ENVIRONMENT
DESIGN AND CONSTRUCTION DIVISION
GEOTECHNICAL BRANCH
MATERIALS TESTING LABORATORY

PROJECT NORTH SASKATCHEWAN RIVER SLOPE STUDY
SITE Slope Movement Area C
HOLE No. BH-C1 ELEV. 639.71 m
LOCATION As shown on Figure 1
TECHNOLOGIST A.S., J.B. DATE DRILLED July, 1984

BOREHOLE AND TEST LOG

TEST RESULTS | DEPTH (m) | SYMBOL | DESCRIPTION | SAMPLE | OTHER INFORMATION

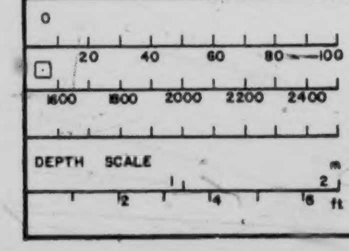


rust stained frac.

SHALE-cl'y, hard, dk gry, coal chips.
SHALE-carb, hard, dk br to blk, coal chips, thin irregular bent'c layer @ approx 175-180mm.
COAL-hard, blk, badly frac, brittle.
SHALE-carb, hard, dk br to blk, badly frac, coal chips, small bent'c, incl from 550-630-bent'c layer @ 565-605.
SHALE-cl'y, hard, dk gry, badly frac, coal chips.

SHALE-cl'y, hard, dk gry, mod frac, coal chips, thin streaks, of bent'c clay sh between 550-610.

Began coring with a CB19-A barrel.



☐	▨	▨	▨	▥	◩	☒
TOPSOIL OR NO SAMPLE	GRAVEL	SAND OR SANDSTONE	CLAY OR SHALE	SILT OR SILTSTONE	UNDISTURBED SAMPLE	DISTURBED SAMPLE

⊙-MOISTURE CONTENT (%), ⊡-WET UNIT WEIGHT (kg/m^3), K-PERMEABILITY (cm/s), F.A-FLIGHT AUGER, HCA-HOLLOW CORE AUGER, ∇ OR S.P.T.-STANDARD PENETRATION TEST BLOW COUNT, PP-POCKET PENETROMETER (kN/m^2), ● OR Qu-UNCONFINED COMPRESSION (kN/m^2), W_P-PLASTIC LIMIT (%) ├──┤ W_L-LIQUID LIMIT (%), ------ CORE RECOVERY (%), 12-0.03-22 -12=% RETAINED ON No.4 SIEVE; 0.03=D_{10} SIZE mm, 22=% No.200 SIEVE, $\frac{40}{35} = \frac{\%\ SILT}{\%\ CLAY}$, ∇̲-WATER LEVEL

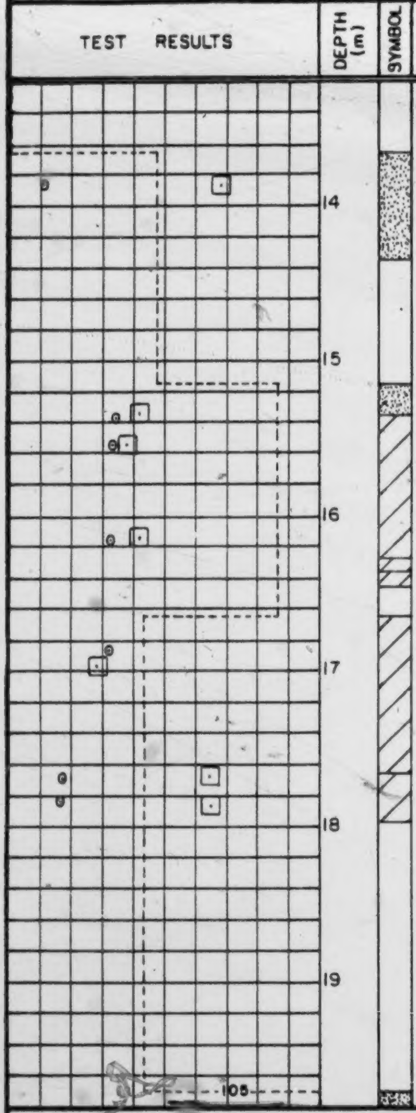
MATTE 1074M

Alberta ENVIRONMENT
DESIGN AND CONSTRUCTION DIVISION
GEOTECHNICAL BRANCH
MATERIALS TESTING LABORATORY

PROJECT NORTH SASKATCHEWAN RIVER SLOPE STUDY
SITE Slope Movement Area C
HOLE No. BH-C1 ELEV. 639.71 m
LOCATION As shown on Figure 1
TECHNOLOGIST A.S., J.B. DATE DRILLED July, 1984

BOREHOLE AND TEST LOG

TEST RESULTS | DEPTH (m) | SYMBOL | DESCRIPTION | SAMPLE | OTHER INFORMATION

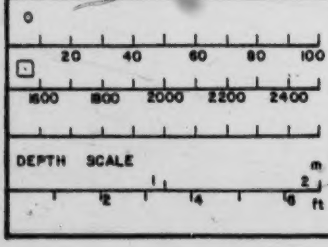


SANDSTONE-very hard, lt gry mod frac,below 310mm,becomes f g with numerous cl'y lams.

as above, f g & finely lam, (possible bent'c).
SHALE-cl'y, hard, dk gry to pale br, badly frac, bent'c.

BENTONITE-hard, olive.
SHALE-cl'y, hard, dk gry,badly frac, coal chips.
SHALE-carb, hard-v hard, dk br badly to mod frac, coal lenses

SHALE-silty, sdy, hard-v hard, lt-med gry, badly to mod frac, sandier with depth.



TOPSOIL OR NO SAMPLE · GRAVEL · SAND OR SANDSTONE · CLAY OR SHALE · SILT OR SILTSTONE · UNDISTURBED SAMPLE · DISTURBED SAMPLE

⊖-MOISTURE CONTENT (%), ⊡-WET UNIT WEIGHT (kg/m^3), K-PERMEABILITY (cm/s), FA-FLIGHT AUGER, HCA-HOLLOW CORE AUGER, ∇ OR S.P.T.- STANDARD PENETRATION TEST BLOW COUNT, PP-POCKET PENETROMETER (kN/m^2), ● OR Qu-UNCONFINED COMPRESSION (kN/m^2), W_p-PLASTIC LIMIT (%) ⊢—⊣ W_L-LIQUID LIMIT (%), ------ CORE RECOVERY (%), 12-0.03-22 -12=% RETAINED ON No.4 SIEVE, 0.03=D_{10} SIZE mm, 22=% No.200 SIEVE, $\frac{40}{35}$ = $\frac{\%\ SILT}{\%\ CLAY}$, ∇- WATER LEVEL

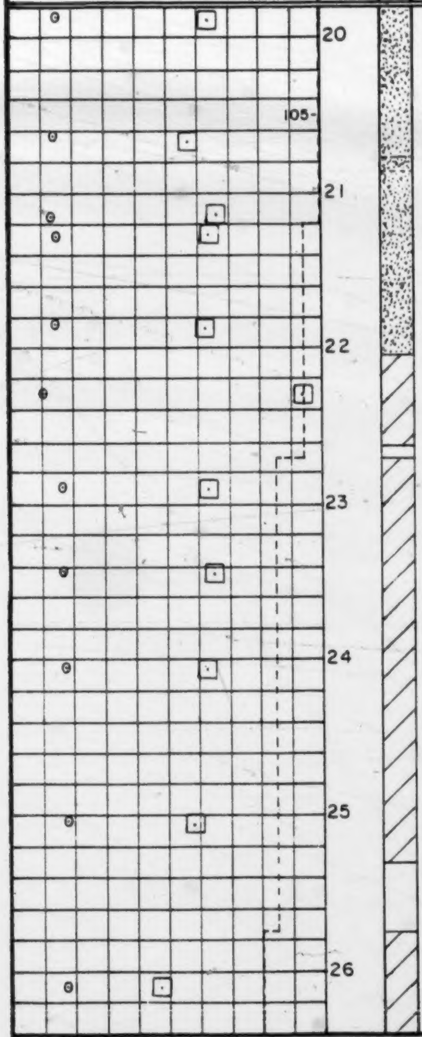
MATTE 1074M

Alberta
ENVIRONMENT
DESIGN AND CONSTRUCTION DIVISION
GEOTECHNICAL BRANCH
MATERIALS TESTING LABORATORY

PROJECT NORTH SASKATCHEWAN RIVER SLOPE STUDY
SITE Slope Movement Area C
HOLE No. BH-C1 ELEV. 639.71 m
LOCATION As shown on Figure 1
TECHNOLOGIST A.S., J.B. DATE DRILLED July, 1984

BOREHOLE AND TEST LOG

TEST RESULTS	DEPTH (m)	SYMBOL	DESCRIPTION	SAMPLE	OTHER INFORMATION



SANDSTONE-hard-v hard, lt gry, mod frac to intact, f-med g, coal lams @ 1080-1170mm.

as above, sh nodules

SHALE-cl'y, hard-v hard, dk gry badly frac.

as above, hard-v hard, crum to mod frac.

as above, hard-v hard, crum to badly frac.

0 20 40 60 80 100
☐ 1600 1800 2000 2200 2400
DEPTH SCALE 1 2 m
2 4 6 ft

☐ TOPSOIL OR NO SAMPLE
▨ GRAVEL
▨ SAND OR SANDSTONE
▨ CLAY OR SHALE
▥ SILT OR SILTSTONE
◿ UNDISTURBED SAMPLE
☒ DISTURBED SAMPLE

Θ-MOISTURE CONTENT (%), ☐-WET UNIT WEIGHT (kg/m^3), K-PERMEABILITY (cm/s), F.A-FLIGHT AUGER, HCA-HOLLOW CORE AUGER, ∇ OR S.P.T.-STANDARD PENETRATION TEST BLOW COUNT, PP-POCKET PENETROMETER (kN/m^2), ● OR Qu-UNCONFINED COMPRESSION (kN/m^2), W_p-PLASTIC LIMIT (%) ├──┤ W_L-LIQUID LIMIT (%), ----- CORE RECOVERY (%), 12-0.03-22 -12= % RETAINED ON No.4 SIEVE, 0.03= D_{10} SIZE mm, 22= % No.200 SIEVE, $\frac{40}{35}$ = $\frac{\%\ SILT}{\%\ CLAY}$, ∇-WATER LEVEL

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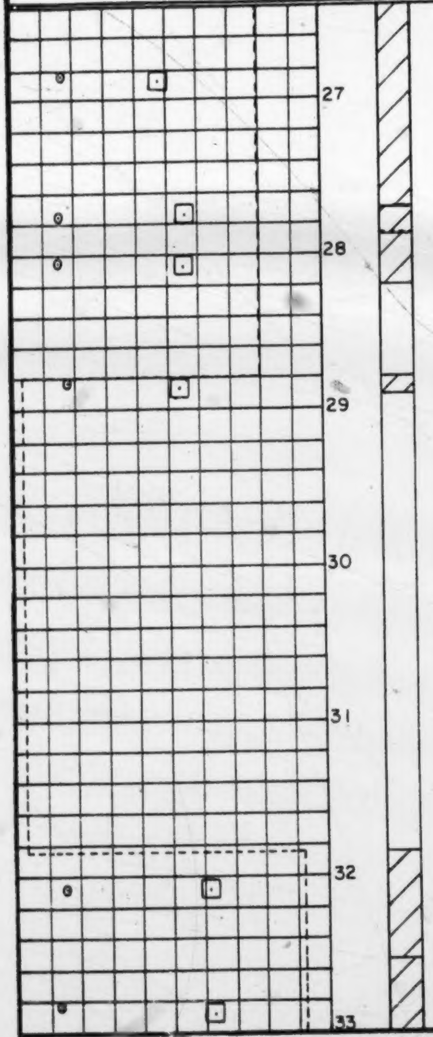
PROJECT NORTH SASKATCHEWAN RIVER SLOPE STUDY
SITE Slope Movement Area C
HOLE No. BH-C1 ELEV. 639.71 m
LOCATION As shown on Figure 1
TECHNOLOGIST A.S., J.B. DATE DRILLED July, 1984

BOREHOLE AND TEST LOG

TEST RESULTS	DEPTH (m)	SYMBOL	DESCRIPTION	SAMPLE	OTHER INFORMATION



SHALE-silty, v hard, med gry, badly to mod frac, ironstone @ 2125.

SHALE-carb, v hard, dk br, badly frac, coal frags & lenses.

SHALE-cl'y, v hard, med gry, badly frac.

as above, hard-v hard, badly to mod frac.

SHALE-silty, sdy, hard-v hard, lt gry, badly frac to intact, int'd clay sh.

○ 0 20 40 60 80 100

▣ 1600 1800 2000 2200 2400

DEPTH SCALE m 1 2
2 4 6 ft

☐ TOPSOIL OR NO SAMPLE
▩ GRAVEL
▒ SAND OR SANDSTONE
▨ CLAY OR SHALE
▥ SILT OR SILTSTONE
◪ UNDISTURBED SAMPLE
☒ DISTURBED SAMPLE

○-MOISTURE CONTENT (%), ▣-WET UNIT WEIGHT (kg/m^3), K-PERMEABILITY (cm/s), F.A.-FLIGHT AUGER, HCA-HOLLOW CORE AUGER, ▽ OR S.P.T.-STANDARD PENETRATION TEST BLOW COUNT, PP-POCKET PENETROMETER (kN/m^2), ● OR Qu-UNCONFINED COMPRESSION (kN/m^2), W_p-PLASTIC LIMIT (%) ├──┤ W_L-LIQUID LIMIT (%), ------ CORE RECOVERY (%), 12-0.03-22 -12=% RETAINED ON No.4 SIEVE, 0.03=D_{10} SIZE mm, 22=% No.200 SIEVE, $\frac{40}{35}$ = $\frac{\% \text{ SILT}}{\% \text{ CLAY}}$, ▽- WATER LEVEL

MATTE 1074M

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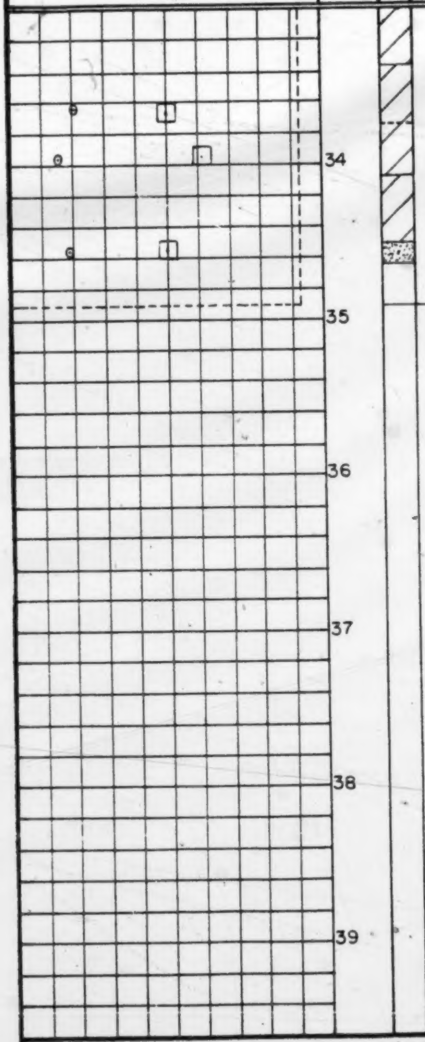
GEOTECHNICAL BRANCH
MATERIALS TESTING LABORATORY

PROJECT NORTH SASKATCHEWAN RIVER SLOPE STUDY
SITE Slope Movement Area C
HOLE No. BH-C1 ELEV. 639.71 m
LOCATION As shown on Figure 1
TECHNOLOGIST A.S., J.B. DATE DRILLED July, 1984

BOREHOLE AND TEST LOG

TEST RESULTS	DEPTH (m)	SYMBOL	DESCRIPTION	SAMPLE	OTHER INFORMATION



SHALE-cl'y, v hard, dk gry to 1880, med gry from 1880, badly to mod frac, sl'ty carb to 1880.

SHALE-silty, sdy, hard-v hard, lt gry, badly frac, int'd clay sh.
SANDSTONE-hard-v hard, lt gry, badly frac, f g, coal lams.

END OF HOLE

0
20 40 60 80 100
⊡
1600 1800 2000 2200 2400

DEPTH SCALE m
1 2
2 4 6 ft

☐ TOPSOIL OR NO SAMPLE
▩ GRAVEL
░ SAND OR SANDSTONE
▨ CLAY OR SHALE
▥ SILT OR SILTSTONE
◪ UNDISTURBED SAMPLE
☒ DISTURBED SAMPLE

⊖-MOISTURE CONTENT (%), ⊡-WET UNIT WEIGHT (kg/m^3), K-PERMEABILITY (cm/s), F.A-FLIGHT AUGER, HCA-HOLLOW CORE AUGER, ∇ OR S.P.T.-STANDARD PENETRATION TEST BLOW COUNT, PP-POCKET PENETROMETER (kN/m^2), ● OR Qu-UNCONFINED COMPRESSION (kN/m^2), W_p-PLASTIC LIMIT (%) ├──┤ W_L-LIQUID LIMIT (%), ------ CORE RECOVERY (%), 12-0.03-22 -12=% RETAINED ON No.4 SIEVE, 0.03=D_{10} SIZE mm, 22=% No.200 SIEVE, $\frac{40}{35} = \frac{\%\ SILT}{\%\ CLAY}$, ∇-WATER LEVEL

containing thin beds of bentonite, coal and ironstone. The surface of this bedrock has been interpreted by Carlson (1967) to be as characterized by a network of preglacial valleys separated by bedrock upland areas. He also indicated that a major preglacial Beverly Valley runs through the entire length of the study area from southwest to northeast.

As reported by Kathol and McPherson (1975) the sequence of surficial deposits overlying bedrock in the Edmonton area ranges in thickness from more than 30 m within the preglacial valleys to less than 5 m over the bedrock upland areas. They noted that the thickest sequence infills the Beverly Valley, where preglacial sand and gravel which rests on bedrock is overlain by till which in turn is overlain by glaciolacustrine sediments to the upland surface. Within the study area, borehole investigations by Thomson (1971), EBA Engineering Consultants Ltd. (1973) and R.M. Hardy & Associates Ltd. (1974, 1976) all encountered a similar sequence of overburden soils. Kathol and McPherson (1975) further reported that outside of the Beverly Valley, the overburden soils are thinnest on the bedrock uplands which are directly overlain by till. Bayrock (1972) and Andriashek and MacMillan (1981) also mapped glaciolacustrine sediments consisting of silty to sandy clays over the majority of the upland surface throughout the study area.

Borehole investigations by the City of Edmonton Materials Testing Division (1970, 1978) and by Underwood McLelland Ltd. (1978, 1980) showed that the low level terraces along the river valley in the upstream end of the study area are veneered with postglacial alluvium. The alluvium encountered was overlying bedrock and consisted of sand and gravel overlain by interbedded silts and clays. Also, colluvium has been mapped by Bayrock (1972) as covering most of the valley slopes through the study area.

Outcrop sections mapped along the river valley and boreholes drilled in the study area by the writer delineated a similar sequence of bedrock strata and overburden soils. The detailed stratigraphic information obtained from this work is described in the following sections in conjunction with pertinent information provided by the previous geological reports.

2.4 Bedrock Geology

Upper Cretaceous bedrock underlying the study area dips gently to the west at approximately 5 m/km (Kathol and McPherson 1975). Outcrops in the study area show that on a local basis the strata are essentially flat lying.

Green (1972) has divided the strata into three formations. The oldest strata occur in the northeast portion of the study area and belong to the Belly River Formation while to the southwest, progressively younger strata of the Bearpaw and Horseshoe Canyon Formations form the bedrock surface. Northwest of the river valley Green (1972) has indicated that these three formations merge to form the Wapiti Formation. As explained by Kathol and McPherson (1975) in this area the Bearpaw Formation has pinched out and the other two formations grade into each other and become indistinguishable.

2.4.1 Belly River Formation

Outcrops of bedrock strata in the study area to the northeast of Sec. 14-54-23-W4 belong to the Belly River Formation. Coring in boreholes BH-B1 and BH-C1 indicates these strata comprise up to three-quarters of the 18 to 39 m high river valley slopes and consist of interbedded silty to clayey shales and sandstone with thin seams of bentonite and coal (Figures 3, 4; 26 and 28).

The silty shale is light to medium grey while the clay shale ranges from being olive-grey and bentonitic shale to dark grey and carbonaceous. In outcrop, the shales break into small, brittle, platy fragments (Figure 5). Samples were usually highly fractured in a similar manner. Core samples from borehole BH-B1 also contained zones of small, randomly-oriented slickensides at depths of 15.1 and 19.3 m . Both zones are 7 m above river level. The shales form layers up to 11 m in thickness with thin bentonite seams up to 100 mm in thickness and coal beds up to 1.2 m in thickness.

Figure 5: Outcrop section in the left flank of a V-shaped gully in SW23-54-23-W4, approximately 280 m downstream of borehole BH-C1. At this location only 6.5 of overburden soils overlies bedrock. strata of the Belly River Formation.

The sandstone is light-grey, fine to medium grained, bentonitic and often contains numerous silty to clayey laminations. In outcrop it forms hard, weather resistant, near vertical faces up to 3 m in thickness (Figure 5).

2.4.2 Bearpaw Formation

Overlying the Belly River Formation to the southwest, Green (1972) has shown that the Bearpaw Formation forms a narrow band of the bedrock surface approximately 1 km wide in Sec.2 to Sec. 11-54-23-W4. Because it occurs in an area with minor slope movement activity, this formation was not mapped in outcrop sections by the writer. Kathol and McPherson (1975) have described these strata as brownish to dark-grey shale interbedded with minor layers of grey sandstone and thin seams of bentonite. However, the specific thicknesses of these layers in the study area is unknown.

2.4.3 Horseshoe Canyon Formation

Green (1972) has depicted the Horseshoe Canyon Formation as forming the bedrock surface in the remaining southwest portion of the study area. The bedrock strata which outcrop in the lower half of the 27 to 33 m high river valley slopes from SW27 to SE34-53-23-W4 are interpreted to belong to this formation. Outcrops of these strata consist primarily of silty to clayey shale with beds of coal and thin seams of bentonite (Figure 77). Subsurface investigations by Thomson (1971) have also encountered bentonitic sandstone interbedded with the shale at the bottom of the slopes at and below river level (Figure 70).

The silty shale is light-grey, while the clay shale is light to dark grey ranging from bentonitic to carbanaceous. In outcrops, the shales occur in layers up to 10 m in thickness with a surficial layer which is weathered to small, brittle platy fragments (Figures 6 and 7). The shale is interbedded with coal beds up to 0.6 m in thickness and seams of bentonite less than 150 mm in thickness.

2.5 Bedrock Topography

Carlson (1967) has interpreted the bedrock surface as a dendritic pattern of valleys formed by the preglacial Beverly Valley and its adjoining tributaries. His bedrock topographic map showed that the Beverly Valley extends eastward beneath Edmonton and then northeastward under the length of the study area. Profiles constructed across this bedrock valley which showed it is up to 13 km wide and 70 m deep with side slopes only locally exceeding 1.5 degrees (~38H:IV).

Carlson (1967) and Kathol and McPherson (1975) have both attributed the formation of the Beverly Valley to a preglacial river which flowed from the Rocky Mountains in an east to northeast direction. The valley was subsequently infilled by preglacial alluvium and glacially derived sediments.

(Carlson 1967) also showed that throughout the study area the North Saskatchewan River valley has been downcut into the broader preglacial Beverly Valley with the river level is 7.6 to 15.2 m above the base of

Figure 6: Displaced overburden soils above insitu shale and coal strata of the Horseshoe Canyon Formation, exposed in a 9 to 10 m high slope below the toe of slope movement SM-E7 in NE27-53-23-W4. Note thin bentonite seam overlying the coal bed.

Figure 7: Displaced blocks of till overlying insitu shale and coal strata of the Horseshoe Canyon Formation, exposed in a 9 to 10 m high slope below the toe of slope movement SM-E13 in SE34-53-23-W4.

the Beverly Valley. Kathol and McPherson (1975) noted that within the Edmonton area postglacial river erosion of the bedrock surface has been limited by the presence of the Beverly Valley. Postglacial erosion of the bedrock has only occurred where the North Saskatchewan River has cut into the sideslopes of the Beverly Valley.

2.6 Surficial Geology

2.6.1 Preglacial Deposits

Bayrock and Berg (1966) and Kathol and McPherson (1975) reported that in the Edmonton area, preglacial sand and gravel alluvium occurs as channel fill deposits in the Beverly Valley. Several variations of an informal formation name has been applied to these sediments in previous reports. Bayrock and Berg (1966) and McPherson and Kathol (1972) used the term Saskatchewan Sands and Gravels, Carlson (1967) used Saskatchewan Sand and Gravel, while Kathol and McPherson (1975) used Saskatchewan gravels and sands. In this study the term Saskatchewan sand and gravel is used as this has an implied pluralism and infers a correlation with similar sediments previously identified in the Edmonton area.

In the upstream end of the of the study area R.M. Hardy & Associates Ltd. (1974, 1976) encountered approximately 20 m of Saskatchewan sand and gravel lying between bedrock and till in boreholes drilled behind the river valley slopes from NE19 to SE30-53-23-W4 (Figure 80). In addition, borehole investigations by Thomson (1971) in the Lesueur Landslide located in SW27-53-23-W4 encountered approximately 6 m of Saskatchewan sand and gravel (Figure 70). An outcrop section mapped by the writer approximately 1.5 km downstream of the Lesueur Landslide in SE34-53-23-W4 exposes up to 9 m of Saskatchewan sand and gravel over bedrock (Figures 8 and 77). Further downstream in the study area at the south end of Fort Saskatchewan, borehole BH-A2 drilled behind the river valley slope in River Lot 15 encountered 15 m of Saskatchewan sand and gravel over bedrock (Figures 2 and 18). In contrast to these occurrences, outcrops and boreholes BH-B1 and BH-C1 along the northwest side of the river valley in the downstream half of the study area show that Saskatchewan sand and gravel are absent or less than 4 m in thickness in these slopes (Figures 3 to 5, 26 and 28).

Typically the sequence of these sediments consists of up to 4.5 m of interbedded sand and gravel overlain by up to 10.5 m of sand. The gravel is composed of quartzite clasts with minor amounts of chert petrified wood, coal and ironstone fragments. The quartzite clasts range up to approximately 150 mm in size, and most of them are subangular to subrounded in shape. The sands are light to greyish brown, fine to coarse grained, often silty and interbedded with thin layers of gravel or clayey to sandy silt. Some layers are massive while others are laminated or display coarse cross-bedding (Figure 9).

2.6.2 Glacial Deposits

In the Edmonton area the glacially derived deposits consist of till overlain by glaciolacustrine sediments which form the upland surface.

Figure 8: Sequence of Saskatchewan sand and gravel exposed in the lower half of a 27 m high river valley slope in SE34-53-23-W4.

Figure 9: Coarsely cross-bedded sand layer of the Saskatchewan sand and gravel exposed in the river valley slopes in SE34-53-23-W4.

Bayrock (1972) attributed the deposition of the till to late Wisconsin continental ice-sheets which advanced over the area from the northeast between 9,000 and 25,000 to 30,000 years ago. The glaciolacustrine sediments were deposited by Glacial Lake Edmonton which formed during the recession of the last ice-sheet from the area.

2.6.2.1 Till

Till occurs in the North Saskatchewan River valley slopes throughout the study area. It overlies the Saskatchewan sand and gravel or rests directly on bedrock where these sediments are absent. Borehole investigations by R.M. Hardy & Associates Ltd. (1974, 1976) have shown that the till attains a thickness of 16.5 m in the upstream end of the study area (Figure 80). Further downstream along the northwest side of the river valley through the W1/2 23-54-23-W4 the thickness of till decreases to approximately 4 m as encountered in borehole BH-C1 and exposed in an adjacent outcrop (Figures 4, 5 and 28). This thin layer of till overlies bedrock which comprises more than three quarters of the 29 to 39 m high river valley slopes along this reach.

The till has a medium to dark-grey colour in an unweathered state as encountered in borehole samples while in outcrops it has a light to buff or yellowish brown colour. Laboratory classification tests of borehole samples indicate the clay matrix is low to medium plastic. In outcrops, rock clasts ranging from pebbles to boulders more than 150 mm in diamter are contained within the till. As well, the till forms near vertical faces that display rectangular or colummnar jointing (Figures 10 and 11).

Numerous lenses and pockets of sand and silt also occur throughout the till. The lenses range in thickness from 1 mm to over 1 m. The sands vary in colour from light yellowish brown to pinkish-brown depending on their mineralogy and degree of oxidation. They are fine to coarse-grained and ofter laminated with layers of silts or clayey silts.

May and Thomson (1979) have discussed the existence of an upper till and lower till deposited from two glacial advances in the Edmonton area. They described the characteristics of the upper till as being yellowish brown, massive and columnar jointed while the lower till was greyish brown, had a rectangular joint system and a tendency to break up into small angular fragments where it is highly fractured.

In contrast only one till in the Edmonton area has been identified by Bayrock and Berg (1966) and Kathol and McPherson (1975). More recently, Catto (1984) identified four diamicton facies in the excavation for the Convention Centre based on structural and lithological criteria, but he interprets these facies to be deposited from one glacial advance.

In the study area there is evidence to suggest that at least in some localities only one till exists based on the criteria of May and Thomson (1979). In an outcrop on the northwest side of the river valley in SE4-54-23-W4 approximately 14 m of a yellowish-brown, massive, columnar-jointed till extends from the underlying Saskatchewan sand and gravel up to the overlying glaciolacustrine sediments indicating that

Figure 10: Glaciolacustrine sediments overlying rectangular jointed till exposed in the main scarp of slope movement SM-C6 in NW23-54-23-W4.

Figure 11: Columnar jointed till overlain by displaced glaciolacustrine sediments exposed in the left flank of slope movement SM-D6 in SE4-54-23-W4. Note sharp contact with underlying Saskatchewan sand and gravel at the bottom of the till.

only the upper till occurs in these slopes (Figure 10). Approximately 4 km further downstream, the slopes from SE22 to NW23-54-23-W4 contain 4 to 7.5 m of till which displays the approximately rectangular jointing of the lower till (Figures 4 and 5).

2.6.2.2 Glaciolacustrine Sediments

Surficial geology maps by Bayrock (1972) and Andriashek and MacMillan (1981) have showed that glaciolacustrine sediments form the upland ground surface throughout the study area. These sediments also occur in outcrop sections along the river valley slopes and in boreholes BH-A2, BH-B1 and BH-C1 (Figures 2 to 4 and 10). The glaciolacustrine sediments overlie till and occur in layers that are up to 6 m in thickness (Figures 18, 26 and 28). Kathol and McPherson (1975) observed that over short distances there are numerous changes in the composition and grain size of the glaciolacustrine sediments. In the study area the composition of these sediments varies between silty clay to silty and clayey sands.

In outcrops the silty clays are light to medium grey but are darker grey in less weathered samples obtained from the boreholes. Laboratory classification tests show they are primarily low to medium plastic. The layers of clay vary from being massive to laminated with dark grey layers of highly plastic clay and light to medium-brown silt. The silty to clayey sands of the glaciolacustrine sediments are light to medium brown and fine to medium grained. The sand layers are often laminated with layers of silt and silty clay and sometimes contain thin discontinuous seams of small pebbles.

2.6.3 Postglacial Deposits

2.6.3.1 Alluvium

Kathol and McPherson (1975) indicated that postglacial granular alluvium occurs in the three terrace levels along the North Saskatchewan River valley in the Edmonton area. Of these the low level terrace at 7 to 8 m above river occurs extensively throughout the study area. Geotechnical site investigations by the City of Edmonton Materials Testing Division (1970, 1978) and Underwood McLellan Ltd. (1978, 1980) have delineated the alluvial sequence in these terraces overlies bedrock and typically consists of 2 to 10.5 m of sand and gravel overlain by 1 to 7 m of interbedded silts and clays.

Deposits of fine alluvium also occur along the floodplains of the tributary creek valleys. These sediments which are probably less than 5 m in thickness consist of interbedded clayey silts and sands with minor amounts of clay and gravel.

2.6.3.2 Colluvium

Bayrock (1972) mapped colluvium derived from gravity-induced movements on most of the valley slopes through the study area. As observed by the writer the thickness of this colluvium depends on the type of movement the slope has experienced. A cover of loose material usually less than 1 m in thickness exists on slopes where shallow surficial movements are occurring while thicker deposits of more than 5 m occur near the toe of the slopes which have undergone block and debris falls and movements seated near river level. The composition of this colluvium varies between intermixed overburden soils and bedrock material depending on the slope stratigraphy.

2.7 Summary

The geology of the study area mapped in the field by the writer is essentially the same as the stratigraphy described in previous reports and maps for the Edmonton area. The only discrepancy noted is with the potential existence of more than one till. As discussed previously in Section 2.6.2.1 only one till appears to exist at least in some outcrops along the river valley slopes. However, the detailed mapping required to accurately distinguish till units is considered to be beyond the scope of this study as the till is geotechnically considered to be one stratigraphic unit as previously indicated by Thomson (1971) and May and Thomson (1979). More detailed mapping as done by Catto (1984) on fresh outcrop sections is required to unravel the depositional history and number of tills in the Edmonton area.

CHAPTER 3

HYDROGEOLOGY

3 1. Previous Work

Reports by Bibby (1974a, 1974b) and Stein (1976) described in detail the hydrogeology of the area covered by the north half of the National Topographic System map sheet 83H which encompasses the study area. Bibby (1974a, 1974b) produced two reports for the northwest segment of this Edmonton area map sheet. One dealt with the regional hydrogeology (Bibby 1974a) while the other dealt with specific aspects of water chemistry and water level distribution between the overburden soils and underlying bedrock strata (Bibby, 1974b). The report by Stein (1976) outlined the regional hydrogeology for the northeast segment of the map sheet. Both Bibby (1974a, 1974b) and Stein (1976) used data available from water well driller reports and oilwell electrologs supplemented by their own well and pump testing program.

Additional hydrogeological information was included in a report by Yoon and Vander Pluym (1974) on the occurence of buried channels in an area bounded by Edmonton, Lac La Biche and Cold Lake. They discussed the hydrogeological characteristics and potential yields of the major aquifers associated with the preglacial bedrock valleys through this area. In particular, they provided information on the buried channel deposits of Saskatchewan sand and gravel within the preglacial Beverly Valley through the study area.

3.2 Groundwater Regime

Bibby (1974a, 1974b) and Stein (1976) interpreted that the regional groundwater movement was towards the North Saskatchewan River valley from surrounding topographically higher areas, with the river valley acting as a discharge area. They also suggested that, recharge of the groundwater in these topographic highs primarily resulted from accumulation of water in local depressions after the spring snowmelt, since most of the summer precipitation is lost to evapotranspiration.

The movement of groundwater towards the river valley was also reported by Bibby (1974a), Stein (1976) and Yoon and Vander Pluym (1974) to have a downward component due to a major aquifer formed by the Saskatchewan sand and gravel buried in the preglacial Beverly Valley, which acts as a line-sink for the area. Yoon and Vander Pluym (1974) further suggested that this downward movement resulted from an underflow in the Beverly Valley aquifer created by natural hydraulic gradient.

Stein (1976) indicated that the downward movement of groundwater is impeded by contrasting permeabilities within the overburden soils resulting in local seepage along the river valley slopes. In the field the writer observed several seepage areas usually along the bottom of the valley slopes near the contact between the Saskatchewan sand and gravel and the underlying bedrock (Figures 12 and 13).

Figure 12: Seepage areas along the toe of the river valley slopes in SE4-54-23-W4.

Figure 13: Seepage areas along toe of the river valley slopes in River Lots 15 and 17 in Fort Saskatchewan.

3.3 Summary

The occurrence of seepage areas near the contact between the bedrock and the overlying Saskatchewan sand and gravel indicates that in the lower half of the slopes the river valley is a discharge and that the sand and gravel acts as an underdrain to aid in drawing down the groundwater towards the river valley. No other features were observed by the writer in the study area to suggest that the hydrogeological conditions are different than that described in the previous reports.

CHAPTER 4

SLOPE MOVEMENTS

4.1. Previous Work

Previous publications on slope movements which covered classification, investigation, analysis and factors influencing instability were compiled by Hoek and Bray (1977) and Schuster and Krizek (1979). In particular, Varnes (1979) summarized a classification system and proposed a nomenclature for the various parts of a slope movement both of which were adopted for this study. As well, in a report on the presentation of engineering geology maps, Dearman (1972) proposed a series of geomorphological and stratigraphic symbols pertinent to slope movement mapping. These symbols which were used in mapping the slope movements of the study area are listed in Figures 14 and 15.

An age classification system for slope movements was devised by McCalpin (1984). He developed four age classes which included active, inactive-young, inactive-mature and inactive-old based on the degree of degradation of geomorphic features and amount of revegetation since movement occurred. McCalpin (1984) also related the four classes to existing slope movements of known or approximated age dating back to the end of the last glaciation which allowed him to provide an absolute age estimate for each class. This system was applied to the slope movements in the study area as described in Table 2.

MICROFILM DATE

1. GENERAL FEATURES

- ▩ MADE GROUND (FILL)
- ▾▾ PONDED WATER
- ⟶ RIVER / CREEK FLOW DIRECTION
- –…➤ INTERMITTENT DRAINAGE
- o➤ SEEPAGE
- ⁞➤ SEEPAGE LINE
- ⌒ FRESHWATER ALLUVIUM
- ⊤⊤⊤⊤ RIVER TERRACE
- ⊕ BOREHOLE
- ▲ ▲ LINE OF PROFILE

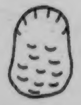
2. SLOPE MOVEMENT FEATURES

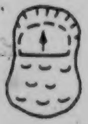
- ⊤⊤⊤⊤ SCARP - SHARP
- ⊤⊤⊤⊤ SCARP - ROUNDED

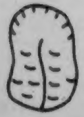
} LENGTH OF DOWNSLOPE LINES INDICATE LENGTH OF SCARP

- -T-T-T- TENSION CRACKS

3. SLOPE MOVEMENT TYPES


SLOPE MOVEMENT - TYPE UNDETERMINED


ROTATIONAL MOVEMENT


TRANSLATIONAL MOVEMENT

DRAWING No.

Alberta
ENVIRONMENT

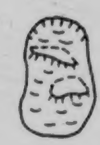
NORTH SASKATCHEWAN RIVER SLOPE STUDY

GEOMORPHOLGICAL SYMBOLS

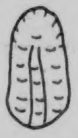
SUBMITTED	DESIGNED	SCALE N/A	SHEET 1 OF 2
DATE	CHECKED	DATE JUNE 1986	FIGURE 14
APPROVED	DRAWN		
DATE	TRACED		

FILE No.

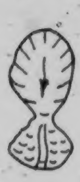
MICROFILM DATE



TRANSLATIONAL BLOCK MOVEMENT



FLOW MOVEMENT



GULLY EROSION / FLOW MOVEMENT

DRAWING No.

Alberta
ENVIRONMENT

NORTH SASKATCHEWAN RIVER SLOPE STUDY

GEOMORPHOLOGICAL SYMBOLS

SUBMITTED
DATE
APPROVED
DATE

DESIGNED
CHECKED
DRAWN
TRACED

SCALE N/A
DATE JUNE 1986

SHEET 2 OF 2
FIGURE 14

FILE No.

MICROFILM, DATE

1. SOIL TYPES

PRIMARY CONSTITUENT		SECONDARY CONSTITUENT		COMBINED SYMBOLS	
▩	GRAVEL	○	GRAVELLY	▒	SAND AND GRAVEL
▒	SAND	░	SANDY	▨	SILTY CLAY
▥	SILT	▥	SILTY	▨	CLAYEY SILT
▨	CLAY	▨	CLAYEY	▨	CLAY TILL

2. BEDROCK TYPES

░	SANDSTONE
▨	SHALE
■	COAL
□	BENTONITE

3. GEOLOGICAL BOUNDARIES AND FEATURES

——— ———	FORMATION CONTACTS
— — — — — —	SOIL TYPE CONTACTS
⏝⏝⏝ ⏝⏝⏝	OVERBURDEN - BEDROCK CONTACT
←	SLICKENSIDES
▽	WATER LEVEL

DRAWING No.

FILE No.

Alberta
ENVIRONMENT

NORTH SASKATCHEWAN RIVER SLOPE STUDY

STRATIGRAPHIC SYMBOLS

SUBMITTED	DESIGNED	SCALE N/A	SHEET 1 OF 1
DATE	CHECKED	DATE JUNE 1986	FIGURE 15
APPROVED	DRAWN		
DATE	TRACED		

TABLE 2 - PRELIMINARY AGE CLASSIFICATION FOR LANDSLIDES (McCalpin, 1984)

AGE CLASS	HEAD SCARP	LATERAL SCARP & DRAINAGE	INTERNAL MORPHOLOGY & DRAINAGE	VEGETATION	TOE RELATIONS	ABSOLUTE AGE
1. Active	Sharp, unvegetated	Sharp, unvegetated, streams at edge.	Undrained depressions, ponds, hummocky topography, angular internal blocks separated by unvegetated cracks.	Absent or sparse on lateral and internal scarps, tilted trees common	Forces stream to opposite valley side where active slides occur, dams drainage, covers modern flood plain, not modified by stream.	Activity within historic time implies less than about 100 years old[a]
2. Inactive-Young	Sharp, partly vegetated	Sharp, partly vegetated, small tributaries to lateral streams	Undrained & drained depressions, ponds, hummocky topography, internal cracks vegetated	Younger than adjacent terrain or different type or density	Same as above but toe may be modified by modern axial channel.	100-5000 years[b]
3. Inactive-Mature	Smooth, vegetated	Smooth, vegetated, tributaries up onto body of slide	No undrained depressions, but smooth rolling topography, drainage network shows derangement	Same age as adjacent terrain but may be different type or density	Cut by modern flood plain meanders; stream not constricted but has widened flood plain	5000-10,000 years[c]
4. Inactive-Old	Dissected, vegetated	Very vague lateral margins, no lateral drainage	No undrained depressions, normal dendritic channels cut into scar or deposit, drainage integrated	Same age, type and density as surrounding terrain	Truncated by stream or overlapped by aggraded terraces	Older than 10,000 years

[a] Definition of Active Landslide: Active within historic time, based on: (1) documentary evidence, (2) eyewitness reports of movement, (3) displacement or disruption of man-made features, OR (4) possession of extremely fresh morphologic features similar to those found in slides with documented historic movement.

[b] 5,000 year older limit tentatively based on charactaristics of the Devils Elbow Rockfall deposit dated at roughly 4120 ± 200 years B.P.

[c] Includes events immediately following the last major glaciation; older limit becomes younger with increasing elevation.

Several studies have delineated the types and causes of slope movements which have occurred along river valleys throughout the Prairie Provinces. Thomson and Morgenstern (1977) investigated the geological and groundwater factors influencing the distribution and types of slope movements prominent in southern Alberta. As well, in a second study, they summarized the type and nature of slope movements seated in the sedimentary bedrock underlying the Prairie Provinces (Thomson and Morgenstern, 1979). Thomson and Bruce (1979) described the types and potential causes of slope movements identified from airphoto interpretation along the North Saskatchewan River valley from Drayton Valley to the Saskatchewan Border. In these three studies predominant factors identified as having an affect on slope movement activity included the occurrence of bentonite or bentonite rich strata in the Upper Cretaceous bedrock, lateral river erosion, and the existence of preglacial valleys floored by permeable sand and gravel which intersected or coincided with the river valleys. It was reported that bentonite and bentonite rich strata formed weak planes and zones with low shearing resistance, lateral river erosion unloaded toes and oversteepened the river valley slopes producing an unstable geometry and the sand and gravel within the preglacial valleys provided a stabilizing effect by underdraining the slope resulting in a lower groundwater table.

Thomson and Townsend (1979) emphasized the importance of geological processes in their report on vertical and lateral erosion rates of the North Saskatchewan River through Edmonton. They cited several case histories of slope movement investigations where lateral river erosion had to be accommodated in the engineering design to stabilize the slopes. Thomson and Tiedemann (1982) discussed how urban development can contribute to instability by affecting the slope geometry and its loading conditions and by raising the groundwater table in a slope.

Previous studies within urban areas of Alberta have provided an inventory of slope movements as a reference for engineering projects and for establishing set-back guidelines since slope movements are often a hazard to existing and future development. Hardy, Clark and Stepanek (1980) summarized the type of slope movements which have occurred along the Bow River and tributary creek valleys within Calgary supported by case histories of the geotechnical investigations undertaken to effect stabilization. For the Edmonton area, Thomson and Yacyshyn (1977) provided an inventory of slope movements along the North Saskatchewan river and tributary creek valleys which included a description of the probable cause of the movements and remedial engineering work required. Mackay and Thomson (1980) delineated and described the slope movements along the South Saskatchewan River and its tributaries through Medicine Hat. A similar study was done by Ruban and Thomson (1983) for the Oldman River and its tributaries through Lethbridge.

Site specific studies within the Edmonton area have included an investigation by Thomson (1970) into the stability of the North Saskatchewan River valley slope below the University of Alberta for a proposed expansion. As well, Thomson (1971) investigated the Lesueur Landslide located northeast of Edmonton in SW27-53-23-W4. This investigation documented important information regarding deformation of the displaced material and the amount of resulting valley crest regression, as the occurrence of the movement was observed by Thomson (1971) on September 3, 1963.

Geotechnical consultants have also performed site specific investigations to assess subsurface stratigraphy and stability conditions of the North Saskatchewan River valley slopes adjacent to proposed residential developments. Of particular relevance were reports by R.M. Hardy & Associates Ltd. (1976) and EBA Consulting Engineering Consultants Ltd. (1973) which summarized slope stability investigations adjacent to the Clareview subdivision in northeast Edmonton and in the Pineview Subdivision in Fort Saskatchewan, respectively.

4.2 Airphoto and Field Mapping

The airphotos used by the writer to delineate the slope movements in the study area are listed in Table 3. Slope movements were first examined for a preliminary assessment of type and age class on the 1980, 1:10,000 airphotos. This was followed by an assessment of past

TABLE 3 - LIST OF AIRPHOTOS

Date	Scale	Numbers	Source
1982	1:30,000	AS 2648-2651	Alberta Energy and Natural Resources, Bureau of Surveying and Mapping
1980	1:10000	AS 2177	Alberta Energy and Natural Bureau of Surveying and
Mapping			
1976	1:8000	G 50702	Geographic Air Survey Ltd.
1975	1:5000	NW 20476, 35576, 41576, 42576	North West Survey Group.
1972	1:31680	AS 1207	Alberta Energy and Natural Resources, Bureau of Surveying and Mapping
1962	1:30680	AS 816-818	Alberta Energy and Natural Resources, Bureau of Surveying and Mapping
1949-50	1:40000	AS 130-135	Alberta Energy and Natural Resources, Bureau of Surveying and Mapping.
1924	1:15840	CA 71, 72, 76, 79	University of Alberta Map Collection; National Airphoto Library

activity and absolute age of the active slope movements from examining five sets of older airphotos ranging in dates from 1982 to 1924, at scales of 1:30,000, 1:31,680, 1:40,000 and 1:15,840. These airphotos were also used to obtain an estimate of valley crest regression where measurable, and in some cases provided evidence for a cause of the slope movement. The data obtained from this airphoto work are listed in Table 4.

Field mapping was subsequently performed by the writer over two and a half months from August to October, 1983. This work involved geomorphological mapping of the slope movements selected from the airphoto work. Mapping was done on airphoto enlargements at a scale of approximately 1:1000 taken from either the 1975, 1:5000 airphotos or 1976, 1:8000 airphotos. At the time of the field work these two sets were required to provide large scale coverage of the entire study area. In addition to geomorphological features the stratigraphy exposed in outcrop sections was mapped as described previously in Section 2.2 of Chapter 2.

Other field work involved traversing a majority of the river valley slopes to inspect the remaining slope movements identified on the airphotos. Some of the tributary creek valleys were also traversed a short distance upstream from the river. Observations and mapping were noted on either the 1975, 1:5000 airphotos or 1976, 1:8000 airphotos depending on the location of the traverse.

TABLE 4 - NORTH SASKATCHEWAN RIVER VALLEY SLOPE MOVEMENT DATA

SLOPE MOVEMENT	LOCATION	TYPE OF MOVEMENT	ABSOLUTE AGE (years)	AGE CLASSIFICATION	PRESENT STATUS OF MOVEMENT	REGRESSION OF VALLEY CREST SINCE 1924 (m)	REMARKS
SLOPE MOVEMENT AREA A:							
SM-A1	River Lot 17 - Ft.Saskatchewan	---	35 - 45	Active	Stabilized	---	Horizontal drain pipe in toe area
SM-A2	River Lot 15 - Ft.Saskatchewan	Translational	5 - 10	Active	Moving	1	
SM-A3	River Lot 15 - Ft.Saskatchewan	Translational	35 - 45	Active	Stabilized	5 - 10	Horizontal drain pipe in toe area
SM-A4	River Lot 15 - Ft.Saskatchewan	Translational	50 - 60	Active	Moving	5 - 10	
SLOPE MOVEMENT AREA B:							
SM-B1	River Lot 12 - Ft.Saskatchewan	---	>60	Inactive Mature	Dormant	None	Terrace of creek alluvium at toe of slope movement
SM-B2	River Lot 10 - Ft.Saskatchewan	---	>60	Inactive Mature	Dormant	None	
SM-B3	River Lot 10 - Ft.Saskatchewan	Compound Rotational-Translational	>60	Inactive Young	Dormant	None	
SM-B4	River Lot 10 - Ft.Saskatchewan	Translational	>60	Active	Moving	---	

TABLE 4 - NORTH SASKATCHEWAN RIVER VALLEY SLOPE MOVEMENT DATA (Cont'd)

SLOPE MOVEMENT	LOCATION	TYPE OF MOVEMENT	ABSOLUTE AGE (years)	AGE CLASSIFICATION	PRESENT STATUS OF MOVEMENT	REGRESSION OF VALLEY CREST SINCE 1924 (m)	REMARKS
SLOPE MOVEMENT AREA C:							
SM-C1	NW14-SW23-54-23-W4	Flow	>60	Active	Moving	5 - 10	Movement initiated by seepage
SM-C2	SW23-54-23-W4	Translational	10	Active	Dormant	<3	
SM-C3	SW23-54-23-W4	Flow	>60	Active	Moving	35 - 45	Movement initiated by gully erosion and seepage on flanks of gully
SM-C4	SW23-54-23-W4	Rotational	>60	Inactive-Young	Dormant	None	
SM-C5	NW23-54-23-W4	Rotational	>60	Inactive-Young	Dormant	None	Secondary slides and falls in toe area being aggravated by river erosion
SM-C6	NW23-54-23-W4	Compound Rotational-Translational	15 - 20	Active	Moving	10 - 15	
SM-C7	SE26-54-23-W4	Compound Rotational-Translational	>60/15-30	Active	Moving	5 - 15	
SM-C8	SE26-54-23-W4	Compound Rotational-Translational	>60	Inactive-Mature	Dormant	None	

TABLE 4 - NORTH SASKATCHEWAN RIVER VALLEY SLOPE MOVEMENT DATA (Cont'd)

SLOPE MOVEMENT	LOCATION	TYPE OF MOVEMENT	ABSOLUTE AGE (years)	AGE CLASSIFICATION	PRESENT STATUS OF MOVEMENT	REGRESSION OF VALLEY CREST SINCE 1924 (m)	REMARKS
SLOPE MOVEMENT AREA C:							
SM-C9	SE26-54-23-W4	Compound Rotational-Translational	>60	Inactive-Mature	Dormant	None	
SM-C10	SE26-54-23-W4	--	>60	Inactive-Mature	Dormant	None	
SM-C11	SE26-54-23-W4	---	>60	Inactive-Mature	Dormant	None	
SLOPE MOVEMENT AREA D:							
SM-D1	SE4-54-23-W4	Translational	>60	Active	Moving	None	
SM-D2	SE4-54-23-W4	---	>60	Inactive-Mature	Dormant	None	
SM-D3	SE4-54-23-W4	Translational	>60	Active	Moving	<5	
SM-D4	SE4-54-23-W4	Translational	>60	Inactive-Young	Dormant	None	
SM-D5	SE4 to NE4 54-22-W4	Translational	>60	Active	Moving	None	
SM-D6	NE4-54-23-W4	Flow	25 - 35	Active	Dormant	3 - 7	Movement initiated by gully erosion
SM-D7	NE4 to NW3 54-3-W4	Translational	>60	Active	Moving	None	

TABLE 4 - NORTH SASKATCHEWAN RIVER VALLEY SLOPE MOVEMENT DATA (Cont'd)

SLOPE MOVEMENT	LOCATION	TYPE OF MOVEMENT	ABSOLUTE AGE (years)	AGE CLASSIFICATION	PRESENT STATUS OF MOVEMENT	REGRESSION OF VALLEY CREST SINCE 1924 (m)	REMARKS
SM-D8	NW3-54-23-W4	Flow	15 - 20	Active	Moving	<1	Movement initiated by seepage
SM-D9	NW3-54-23-W4	---	>60	Active	Moving	None	
SM-D10	NW3-54-23-W4	---	>60	Inactive-Young	Dormant	None	Movement initiated by gully erosion
SLOPE MOVEMENT AREA E:							
SM-E1	SW27-53-23-W4	Translational	21	Active	Dormant	15	Lesueur Landslide (Thomson, 1971)
SM-E2	SW27-53-23-W4	---	>60	Inactive-Mature	Dormant	None	
SM-E3	SE27-53-23-W4	Translational	35 - 60	Active	Dormant	<5	Secondary flow movements in toe area due to seepage
SM-E4	SE27-53-23-W4	Translational	35 - 60	Active	Dormant	10	
SM-E5	SE27-53-23-W4	---	>60	Inactive-Young	Dormant	None	
SM-E6	NW27-53-23-W4	Flow	15 - 25	Active	Moving	<3	Movement Initiated by gully erosion and seepage
SM-E7	NE27-53-23-W4	Compound Rotational - Translational	>60	Inactive-Mature	Dormant	None	Secondary flow movements in toe area initiated by seepage

TABLE 4 - NORTH SASKATCHEWAN RIVER VALLEY SLOPE MOVEMENT DATA (Cont'd)

SLOPE MOVEMENT	LOCATION	TYPE OF MOVEMENT	ABSOLUTE AGE (years)	AGE CLASSIFICATION	PRESENT STATUS OF MOVEMENT	REGRESSION OF VALLEY CREST SINCE 1924 (m)	REMARKS
SLOPE MOVEMENT AREA E:							
SM-E8	NE27-53-23-W4	---	>60	Inactive-Mature	Dormant	None	
SM-E9	NE27-53-23-W4	---	>60	Inactive-Mature	Dormant	None	Secondary flow movements in toe area initiated by seepage
SM-D10	SE34-53-23-W4	Flow	35 - 60	Active	Dormant	<1	Movement initiated by gully erosion
SM-E11	SE34-53-23-W4	---	>60	Inactive-Mature	Dormant	None	
SM-E12	SE34-53-23-W4	Flow	35 - 60	Active	Moving	None	Movement initiated by seepage
SM-E13	SE34-53-23-W4	---	>60	Inactive-Mature	Dormant	None	
SLOPE MOVEMENT AREA F:							
SM-F1	NE19 to SW 29-53-23-W4	Compound Rotational - Translational	>60	Inactive-Mature	Dormant	None	
SM-F2	NW29-53-23-W4	Compound Rotational - Translational	>60	Inactive-Mature	Dormant	None	
SM-F3	NW28-53-23-W4	Compound Rotational - Translational	>60	Inactive-Mature	Dormant	None	

Airphoto drawings showing the geomorphological mapping, profiles showing stratigraphy and photographs of the slope movements are presented as Figures 16 to 84 in Sections 4.3.1 to 4.3.6 along with a description of the slope movements.

In the field profiles were surveyed with a hand-level by the writer or by an Alberta Environment survey crew using a Hewlett Packard 3810 Total Station Electronic Distance Measuring (EDM) instrument. Profiles were also constructed from 1:5000 Cadastral contour maps and in a few cases from 1:25000 National Topographic Maps. (Ecological Land Surveys Ltd. 1984; Canada Department of Engergy, Mines and Resources, 1973). The slope height and inclination data obtained from these profiles are listed in Tables 5 and 6, along with a simplified description of the slope stratigraphy. Elevations of the North Saskatchewan River level taken from the Cadastral maps were used as a datum for the slope height and stratigraphy.

In Boreholes BH-A2, BH-B1 and BH-C1, 25.4 mm diameter PVC standpipe piezometers were installed to obtain a preliminary assessment of the groundwater conditions. As the groundwater table was suspected of being near the river level the piezometer tips were set at the bottom of the hole which ended in bedrock. The length of the slotted tips varied from 3 m in BH-A2 to 6.1 m in BH-B1 and BH-C1. The boreholes were backfilled with pea gravel around the standpipe and plugged at the ground surface with bentonite and auger

TABLE 5 - NORTH SASKATCHEWAN RIVER VALLEY SLOPE DATA

LOCATION	DESCRIPTION/ SLOPE MOVEMENT	SLOPE HEIGHT H_S- (m)	SLOPE INCLINATION α-(degrees)	DISPLACED MATERIAL	SIMPLIFIED STRATIGRAPHY (STRATGRAPHIC CATEGORY)
SLOPE MOVEMENT AREA A:					
River Lot 19 - Ft.Saskatchewan	Abandoned valley slopes upstream of Slope Movement Area A	11	25	--	Slopes comprised of overburden soils with the overburden-bedrock contact at approximately 4 m below river level (Stratigraphic Category 1)
River Lot 19 - Ft.Saskatchewan	Abandoned valley slopes upstream of Slope Movement Area A	11	20	--	
River Lot 17 - Ft.Saskatchewan	Abandoned valley slopes upstream of	11	26	--	
River Lot 17 - Ft.Saskatchewan	SM-A1	24	30	Overburden soils	
River Lots 15 & 17 - Ft.Saskatchewan	A_{S1}- Slopes along river between SM-A1 and SM-A2	22	45	--	
River Lot 15 - Ft.Saskatchewan	SM-A2	24	45	Overburden soils	
River Lot 15 - Ft.Saskatchewan	SM-A3	23	--	Overburden soils	
River Lot 15 - Ft.Saskatchewan	A_{S2} - Slopes along river between SM-A3 and SM-A4	22	38	--	
River Lot 15 - Ft.Saskatchewan	SM-A4	23	34	Overburden soils	

TABLE 5 - NORTH SASKATCHEWAN RIVER VALLEY SLOPE DATA (Cont'd)

LOCATION	DESCRIPTION/ SLOPE MOVEMENT	SLOPE HEIGHT H_s-(m)	SLOPE INCLINATION α-(degrees)	DISPLACED MATERIAL	SIMPLIFIED STRATIGRAPHY (STRATGRAPHIC CATEGORY)
SLOPE MOVEMENT AREA A:					
Approx. 300 m Northeast of Hwy 15 - Ft.Saskatchewan	Abandoned Valley Slopes Downstream of Slope Movement Area A	12	18	--	Slopes comprised of overburden soil with the overburden-bedrock contact at approximately 4 m below river level (Stratigraphic Category 1)
Approx. 525 m Northeast of Hwy 15 - Ft.Saskatchewan	Abandoned Valley Slopes Downstream of Slope Movement Area A	12	10	--	
Approx. 850 m northeast of Hwy 15 - Ft.Saskatchewan	Abandoned Valley Slopes Downstream of Slope Movement Area A	11	15	--	
SLOPE MOVEMENT AREA B:					
River Lot 22 - Ft.Saskatchewan	Abandoned Valley Slopes Upstream of Slope Movement Area B	12	8	--	Slopes comprised of overburden soils and bedrock with their contact at approximately 9 m above river level (Stratigraphic Category 2)
River Lot 14 - Ft.Saskatchewan	Abandoned Valley Slopes Upstream of Slope Movement Area B	18	10	--	
River Lot 12 - Ft.Saskatchewan	SM-B1	20	12	Overburden soils and bedrock material	
River Lot 10 - Ft.Saskatchewan	SM-B2	18	--	Overburden soils and bedrock material	

TABLE 5 - NORTH SASKATCHEWAN RIVER VALLEY SLOPE DATA (Cont'd)

LOCATION	DESCRIPTION/ SLOPE MOVEMENT	SLOPE HEIGHT H_s-(m)	SLOPE INCLINATION α-(degrees)	DISPLACED MATERIAL	SIMPLIFIED STRATIGRAPHY (STRATGRAPHIC CATEGORY)
SLOPE MOVEMENT AREA B (cont'd):					
River Lot 10 - Ft.Saskatchewan	SM-B3	18	22	Overburden soils and bedrock material	Slopes comprised of overburden soils and bedrock with their contact at approximately 9 m above river level (Stratigraphic Category 2)
River Lot 10 - Ft.Saskatchewan	SM-B4	19	25	Overburden soils and bedrock material	
River Lot 8 - Ft.Saskatchewan	Abandoned valley slopes downstream of Slope Movement Area B	12	15		
SLOPE MOVEMENT AREA C:					
NW14-54-23-W4	Abandoned valley slopes upstream of Slope Movement Area C	10	15		Slopes comprised primarily of bedrock with the overburden-bedrock contact at approximately 32 m above river level (Stratigraphic Category 3)
NW14-54-23-W4	Abandoned valley slopes upstream of Slope Movement Area C	24	18		
NW14-54-23-W4	Abandoned valley slopes upstream of Slope Movement Area C	28	27		
NW14-54-23-W4	SM-C1	39	27.5	Primarily bedrock material	

TABLE 5 - NORTH SASKATCHEWAN RIVER VALLEY SLOPE DATA (Cont'd)

LOCATION	DESCRIPTION/ SLOPE MOVEMENT	SLOPE HEIGHT H_s-(m)	SLOPE INCLINATION α-(degrees)	DISPLACED MATERIAL	SIMPLIFIED STRATIGRAPHY (STRATGRAPHIC CATEGORY)
SLOPE MOVEMENT AREA C (cont'd):					
SW23-54-23-W4	SM-C2	38	--	Bedrock material	Slopes comprised primarily of bedrock with the overburden-bedrock contact at approximately 32 m above river level (Stratigraphic Category 3)
SW23-54-23-W4	SM-C3	37	20	Overburden soils and bedrock material	
SW23-54-23-W4	C_s - Slopes along river between SM-C3 and SM-C4	38	25		
SW23-54-23-W4	SM-C4	35	27	Overburden soils	Slopes comprised primarily of bedrock with the overburden-bedrock contact at approximately 26 m above river level (Stratigraphic Category 3)
NW23-54-23-W4	SM-C5	37	20	Overburden soils and bedrock material	
NW23-54-23-W4	SM-C6	36	21	Overburden soils	
SE26-54-23-W4	SM-C7	36	18	Overburden soils and bedrock material	
SE26-54-23-W4	SM-C8	33	27	Overburden soils	

TABLE 5 - NORTH SASKATCHEWAN RIVER VALLEY SLOPE DATA (Cont'd)

LOCATION	DESCRIPTION/ SLOPE MOVEMENT	SLOPE HEIGHT H_S-(m)	SLOPE INCLINATION α-(degrees)	DISPLACED MATERIAL	SIMPLIFIED STRATIGRAPHY (STRATGRAPHIC CATEGORY)
SLOPE MOVEMENT AREA C (cont'd):					
SE26-54-23-W4	SM-C9	31	26	Overburden soils and bedrock material	Soils comprised primarily of bedrock with the overburden-bedbock contact at approximately 26 m above river level (Stratigraphic Category 3)
SE26-54-23-W4	SM-C10	29	26	--	
SE26-54-23-W4	SM-C11	30	27	--	
SW25-54-23-W4	Abandoned valley slopes downstream of Slope Movement Area C	13	23	--	
SW25-54-23-W4	Abandoned valley slopes downstream of Slope Movement Area C	12	23	--	
River Lot 30 - Ft.Saskatchewan	Abandoned valley slopes downstream of Slope Movement Area C	13	17	--	
SLOPE MOVEMENT AREA D:					
SW33-53-23-W4	Abandoned valley slopes upstream of Slope Movement Area D	17	14	--	Slopes comprised of overburden soils with the overburden-bedrock contact at 5 m to 10 m below Rrver level (Stratigraphic Category 1)
SE4-54-23-W4	SM-D1	35	30	Overburden soils	
SE4-54-23-W4	SM-D2	34	--	Overburden soils	

TABLE 5 - NORTH SASKATCHEWAN RIVER VALLEY SLOPE DATA (Cont'd)

LOCATION	DESCRIPTION/ SLOPE MOVEMENT	SLOPE HEIGHT H_s-(m)	SLOPE INCLINATION α-(degrees)	DISPLACED MATERIAL	SIMPLIFIED STRATIGRAPHY (STRATGRAPHIC CATEGORY)
SLOPE MOVEMENT AREA D (cont'd):					
SE4-54-23-W4	SM-D3	34	35	Overburden Soils	Slopes comprised of overburden soils with the overburden-bedrock contact at 5 m to 10 m below river level (Stratigraphic Category 1)
SE4-54-23-W4	SM-D4	29	38	Overburden Soils	
SE4 to NE 4 - 54-23-W4	SM-D5	31	37	Overburden Soils	
NE4-54-23-W4	SM-D6	29	--	Overburden Soils	
NE4 to SW 3-54-23-W4	SM-D7	30	38	Overburden Soils	
NW3-54-23-W4	SM-D8	29	--	Overburden Soils	
NW3-54-23-W4	SM-D9	28	30	Overburden Soils	
NW3-54-23-W4	SM-D10	27	--	--	
NW11-54-23-W4	D_s-Slopes along river downstream of Slope Movement Area D	24	32	--	
SE10-54-23-W4	Abandoned valley slopes downstream of Slope Movement Area D	17	23	--	
SE10-54-23-W4	Abandoned valley slopes downstream of Slope Movement Area D	19	23	--	

TABLE 5 - NORTH SASKATCHEWAN RIVER VALLEY SLOPE DATA (Cont'd)

LOCATION	DESCRIPTION/ SLOPE MOVEMENT	SLOPE HEIGHT H_s-(m)	SLOPE INCLINATION α-(degrees)	DISPLACED MATERIAL	SIMPLIFIED STRATIGRAPHY (STRATGRAPHIC CATEGORY)
SLOPE MOVEMENT AREA E:					
NW22-53-23-W4	Abandoned valley slopes upstream of Slope Movement Area E	22	15	--	Slopes comprised of overburden soils and bedrock with their contact at approximately 15 m above river level (Stratigraphic Category 2)
SW21-53-23-W4	Abandoned valley slopes upstream of Slope Movement Area E	14	10	--	
NW22-53-23-W4	Abandoned valley slopes upstream of Slope Movement Area E	25	10	--	
SW27-53-23-W4	SM-E1	30	17	Overburden soils and bedrock material	
SW27-53-23-W4	SM-E2	32	22	Overburden soils and bedrock material	
SE27-53-23-W4	SM-E3	33	20	Overburden soils and bedrock material	
SE27-53-23-W4	SM-E4	32	22	Overburden soils and bedrock material	
SE27-53-23-W4	SM-E5	34	28	Overburden soils and bedrock material	

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TABLE 5 - NORTH SASKATCHEWAN RIVER VALLEY SLOPE DATA (Cont'd)

LOCATION	DESCRIPTION/ SLOPE MOVEMENT	SLOPE HEIGHT H_s-(m)	SLOPE INCLINATION α-(degrees)	DISPLACED MATERIAL	SIMPLIFIED STRATIGRAPHY (STRATGRAPHIC CATEGORY)
SLOPE MOVEMENT AREA E (cont'd):					
NW26-53-23-W4	SM-E6	29	--	Overburden soils and bedrock material	Slopes comprised of overburden soils and bedrock with their contact at approximately 7 m above river level (Stratagraphic Category 2)
NE27-53-23-W4	SM-E7	29	22	Overburden soils	
NE27-53-23-W4	SM-E8	30	--	Overburden soils	
NE27-53-23-W4	SM-E9	30	28	Overburden soils	
SE34-53-23-W4	SM-E10	30	--	--	
SE34-53-23-W4	SM-E11	29	--	Overburden soils	
SE34-53-23-W4	SM-E12	29	38	Bedrock material	
SE34-53-23-W4	SM-E13	28	30	Overburden soils	
SE34-53-23-W4	E_S-Slopes along river downstream from SM-E13	27	35	--	
NE35-53-23-W4	Abandoned valley slopes downstream of Slope Movement Area E	12	13	--	

TABLE 5 - NORTH SASKATCHEWAN RIVER VALLEY SLOPE DATA (Cont'd)

LOCATION	DESCRIPTION/ SLOPE MOVEMENT	SLOPE HEIGHT H_s-(m)	SLOPE INCLINATION α-(degrees)	DISPLACED MATERIAL	SIMPLIFIED STRATIGRAPHY (STRATGRAPHIC CATEGORY)
SLOPE MOVEMENT AREA F:					
SE19-53-23-W4	Abandoned valley slopes upstream of Slope Movement Area F	28	25	--	Slopes comprised of overburden soils with the overburden-bedrock contact at approximately 2 m below river level (Stratigraphic Category 1)
NE19-53-23-W4	Abandoned valley slopes upstream of Slope Movement Area F	27	30	--	
NE19 to SW29-53-23-W4	SM-F1	39	25	Overburden soils	
NW29-53-23-W4	SM-F2	37	24	Overburden soils	
NE29-53-23-W4	F_s1-Slopes along river from SM-F2 Downstream to Sec.28-53-23-W4	34	34	--	
NE29-53-23-W4	F_s2-Slopes along river in Sec.28-53-23-W4	34	34	--	
NE28-53-23-W4	SM-F3	33	25	Overburden soils	
NE28-53-23-W4	Abandoned valley slopes downstream of Slope Movement Area F	14	14	--	
NE28-53-23-W4	Abandoned valley slope downstream of Slope Movement Area F	9	14	--	
NE28-53-23-W4	Abandoned valley slope downstream of Slope Movement Area F	12	12	--	

TABLE 6 - TRIBUTARY CREEK VALLEY SLOPE DATA

LOCATION	DESCRIPTION	SLOPE HEIGHT H_s (m)	SLOPE INCLINATION α-(degrees)	INFERRED STRATIGRAPHY (STRATIGRAPHIC CATEGORY)
HORSEHILLS CREEK VALLEY:				
SE4-54-23-W4	H_S-South slope of creek valley	25	31	Slopes comprised of overburden soils with the overburden-bedrock contact below creek level as inferred from Slope Movement Area D (Stratigraphic Category 1)
SE4-54-23-W4	H_N-North slope of creek valley	28	40	
UNNAMED CREEK VALLEY (T2):				
NW23-54-23-W4	$T2_{SW}$-Southwest slope of creek valley	28	30	Slopes comprised primarily of bedrock with overburden-bedrock contact in the upper half of the slopes as inferred from Slope Movement Area C (Stratigraphic Category 3)
NW23-54-23-W4	$T2_{NE}$-Northeast slope of creek valley	27	21	
UNNAMED CREEK VALLEY (T3):				
SW26-53-23-W4	$T3_{SW}$-Southwest slope of creek valley	21	24	
SW26-54-23-W4	$T3_{NE}$-Northeast slope of	21	20	
NORTH CREEK VALLEY:				
SE26-54-23-W4	N_{SW}-Southwest slope of creek valley	25	23	
SE26-54-23-W4	N_{NE}-Northeast slope of creek valley	26	23	

TABLE 6 - TRIBUTARY CREEK VALLEY SLOPE DATA (Cont'd)

LOCATION	DESCRIPTION	SLOPE HEIGHT H_s (m)	SLOPE INCLINATION α-(degrees)	INFERRED STRATIGRAPHY (STRATIGRAPHIC CATEGORY)
UNNAMED CREEK VALLEY (T1):				
SE27-53-23-W4	$T1_{SW}$- Southwest slope of creek valley	22	31	Slopes comprised of overburden soils and bedrock with their contact in the lower half of the slopes inferred from Slope Movement Area E (Stratigraphic Category 2)
SE27-52-34-W4	$T1_{NE}$ - Northeast slope of creek valley	22	32	
OLDMAN CREEK VALLEY:				
SE27-53-23-W4	O_{SW}-Southwest slope of creek valley	23	12	
SE27-53-23-W4	O_{NE}-Northeast slopes of creek valley	24	21	
POINTE-AUX-PINS CREEK VALLEY:				
SW1-54-23-W4	Southwest slope of creek valley	12	16	
SW1-54-23-W4	Northeast slope of creek valley	15	32	
ROSS CREEK VALLEY:				
River Lot 5 Ft.Saskatchewan	West slope of creek valley	11	8	
River Lot 5 Ft.Saskatchewan	East slope of creek valley	10	18	

cuttings. Since their installation water levels have been read six times over the past year and a half as listed in Table 7.

4.3 North Saskatchewan River Valley Slope Movements

Among the 45 slope movements identified along the oversteepened slopes bordering the North Saskatchewan River, 31 revealed evidence of their probable type of movement (Table 4). These movements occur in groups, along the outside of meanders, after bends in the river and opposite islands. These groups are designated as Slope Movement Areas A to F shown on Figure 1 in Appendix 1. From the upstream end of each Area the slope movements are numbered consecutively in the downstream direction (e.g. SM-A1 to SM-A4) as outlined on Figures 101 to 115 in Appendix 1. Selected slope movements from each Area are discussed in Section 4.3.1 to 4.3.5.

Along the abandoned river valley slopes which rise above the low-level terraces there is an absence of slope movements which can be classed as active or inactive-young. As outlined on Figures 101 to 115 in Appendix 1, only inactive-mature movements occur along these slopes.

4.3.1 Slope Movement Area A

Slope Movement Area A encompasses the slopes on the southeast side of the river valley through River Lots 15 and 17 at the south end of Fort Saskatchewan (Figures 1 and 111; Appendix 1). Through this

TABLE 7 - PIEZOMETRIC WATER LEVELS

BOREHOLE	ELEVATION (m)	SLOPE HEIGHT (m)	DATE:	DEPTH OF WATER LEVEL (m)								
				83-12-06	83-12-14	84-01-04	84-03-09	84-04-04	84-05-18	85-04-15	85-05-06	AVERAGE
BH-A2	621.72	24		21.35	--	--	--	20.50	22.02	Plugged	--	21.29
BH-B1	621.80	20				7.60	6.85	--	7.60	4.04	5.54	6.33
BH-C1	639.71	39			--	--	27.75	27.40	27.60	27.29	27.86	27.58

area the valley slopes rise 22 to 24 m above the river which is at an elevation of approximately 600 m. A gentle bend 0.8 km upstream, directs the main current of the river along the toe of the slopes.

As mapped on Figure 16 and summarized in Table 4, slope movements designated SM-A1 to SM-A4 occur in Area A. Profiles of slope movements SM-A1, SM-A2 and SM-A4 are shown on Figures 17, 18 and 21 while Figures 19, 20 and 22 to 24 are photographs of SM-A2 and SM-A4 and their features.

The subsurface stratigraphy encountered in borehole BH-A2 indicates that Saskatchewan sand and gravel comprise almost half of the slopes in Area A extending to approximately 11 m above river level (Figure 18). At this location these sediments are primarily sands which become gravelly with depth. They overlie interbedded sandstone and clay shale of the Belly River Formation at a depth of 4 m below river level and are overlain themselves by 8.5 m of clay till. The till contains lenses of silty to gravelly sand and is overlain by 2.5 m of silty to clayey glaciolacustrine sediments which form the upland surface. Water level in BH-A2 and seepage areas along the toe of the slopes indicate that the groundwater table is 1 to 3 m above river level in the Saskatchewan sand and gravel (Table 7; Figures 13 and 18). Similar stratigraphy and groundwater conditions were encountered by EBA Engineering Consultants Ltd. (1973) during their stability investigation of these slopes.

MICROFILM DATE

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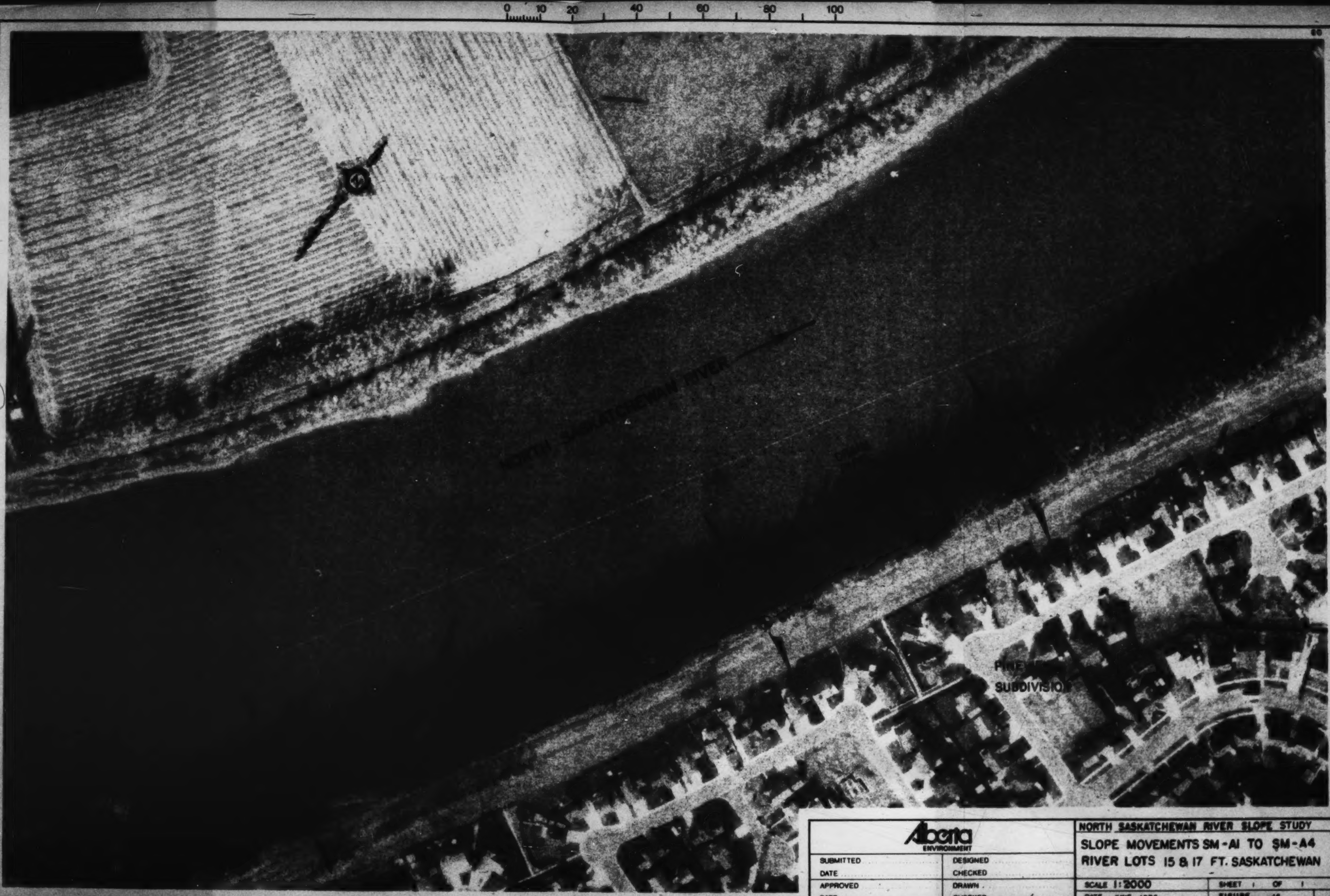
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NORTH SASKATCHEWAN RIVER
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ENVIRONMENT

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

SLOPE MOVEMENTS SM-AI TO SM-A4
RIVER LOTS 15 & 17 FT. SASKATCHEWAN

SCALE 1:2000	SHEET 1 OF 1
DATE JUNE 1986	FIGURE 16

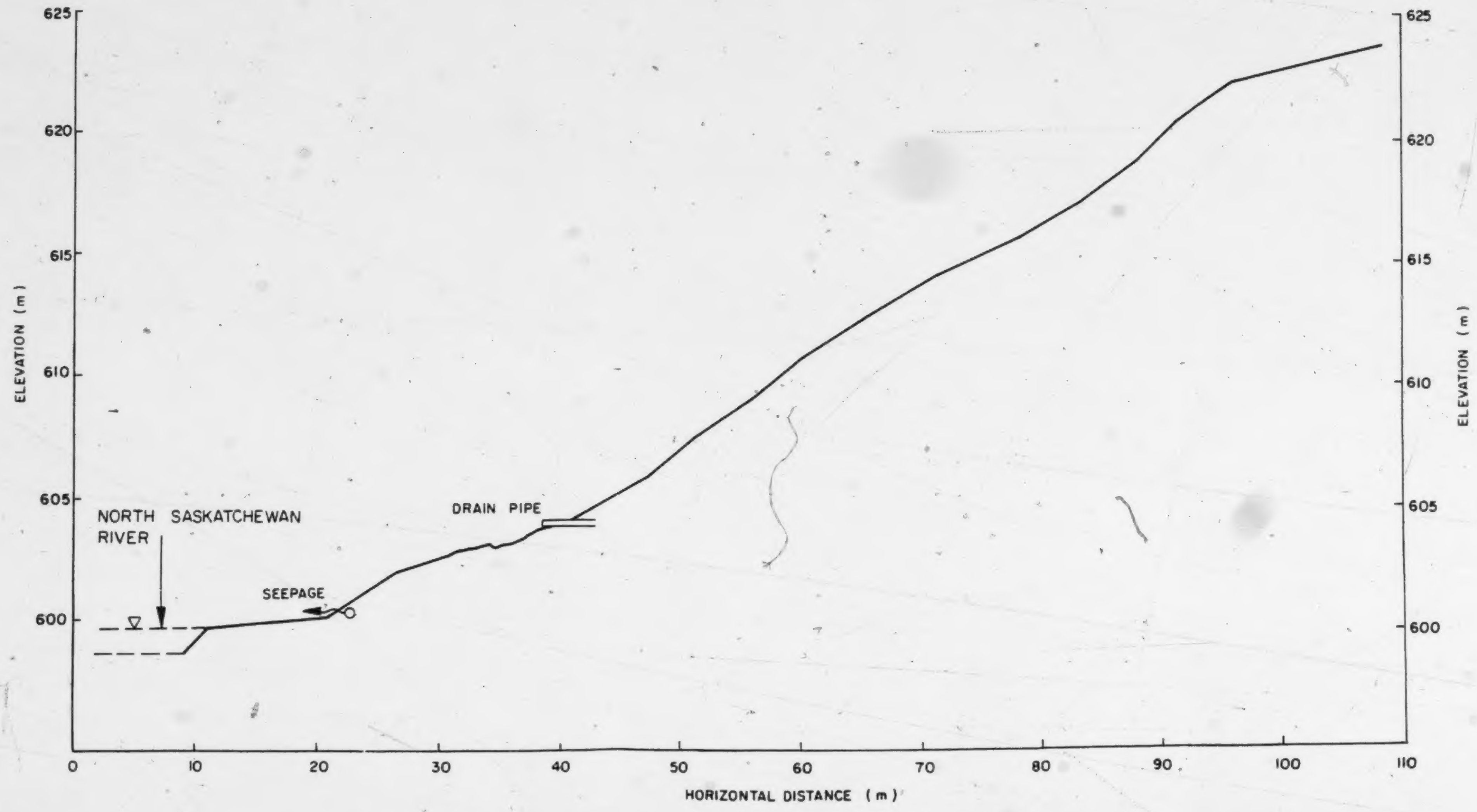
0 10 20 40 60 80 100

MICROFILM DATE

DRAWING FILE No

CENTRAL FILE No

NOTE:
PROFILE CONSTRUCTED FROM HAND - LEVEL SURVEY.



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NORTH SASKATCHEWAN RIVER SLOPE STUDY

PROFILE OF SLOPE MOVEMENT SM - A1

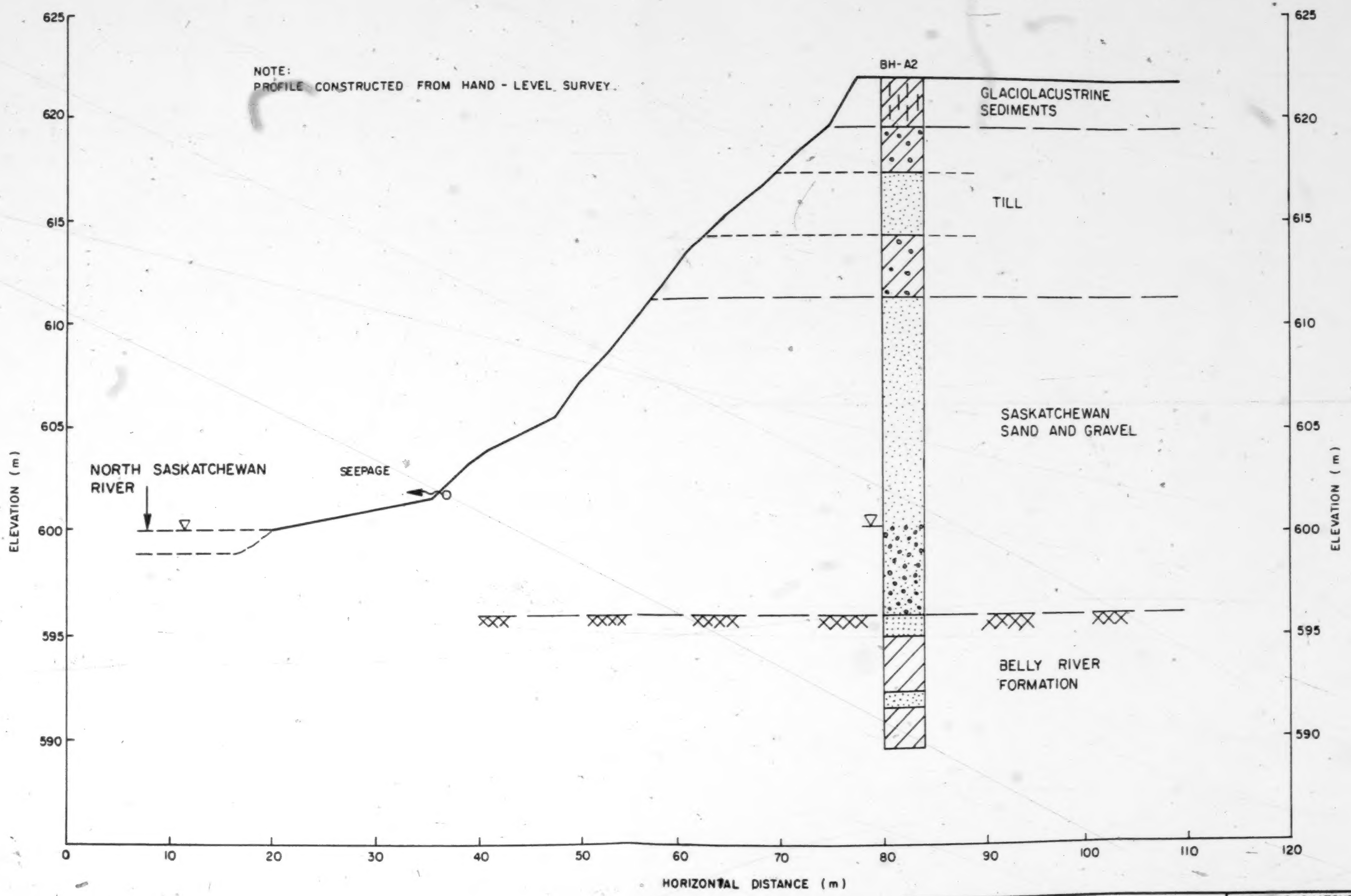
SCALE AS SHOWN (V=2H)
SHEET 1 OF 1
DATE JUNE 1986
FIGURE 17

P3-280x430

MICROFILM DATE

DRAWING FILE No.

CENTRAL FILE No.


NOTE:
PROFILE CONSTRUCTED FROM HAND - LEVEL SURVEY.
BH-A2
GLACIOLACUSTRINE SEDIMENTS
TILL
SASKATCHEWAN SAND AND GRAVEL
BELLY RIVER FORMATION
NORTH SASKATCHEWAN RIVER
SEEPAGE
ELEVATION (m)
625
620
615
610
605
600
595
590
HORIZONTAL DISTANCE (m)
0
10
20
30
40
50
60
70
80
90
100
110
120

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DATE	CHECKED

NORTH SASKATCHEWAN RIVER SLOPE STUDY

PROFILE OF SLOPE MOVEMENT SM-A2

SCALE AS SHOWN (V=2H)	SHEET 1 OF 1
DATE JUNE 1986	FIGURE 18

P3-280x430

Figure 19: View of slope movement SM-A2 from the opposite side of the North Saskatchewan River.

Figure 20: Displaced overburden soils at toe of SM-A2. Note small bank undercut by river erosion.

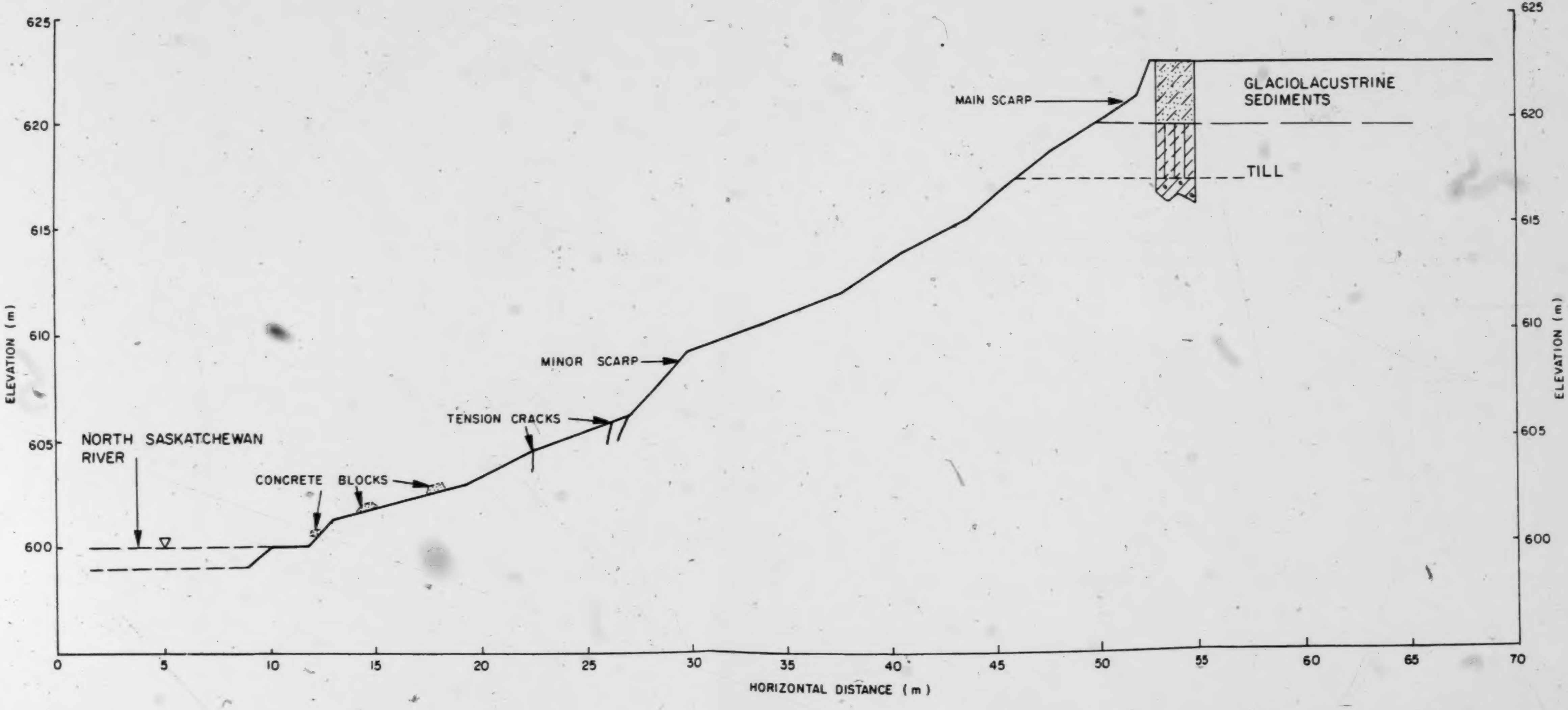
0 10 20 40 60 80 100

MICROFILM DATE

DRAWING FILE No

CENTRAL FILE No

NOTES:
1. STRATIGRAPHY MAPPED FROM OUTCROP SECTION IN MAIN SCARP.
2. PROFILE CONSTRUCTED FROM HAND - LEVEL SURVEY.



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NORTH SASKATCHEWAN RIVER SLOPE STUDY

PROFILE OF SLOPE MOVEMENT SM - A4

SCALE AS SHOWN
DATE JUNE - 1986
SHEET 1 OF 1
FIGURE 21

P3-280×430

Figure 22: View of slope movement SM-A4 from the opposite side of the North Saskatchewan River.

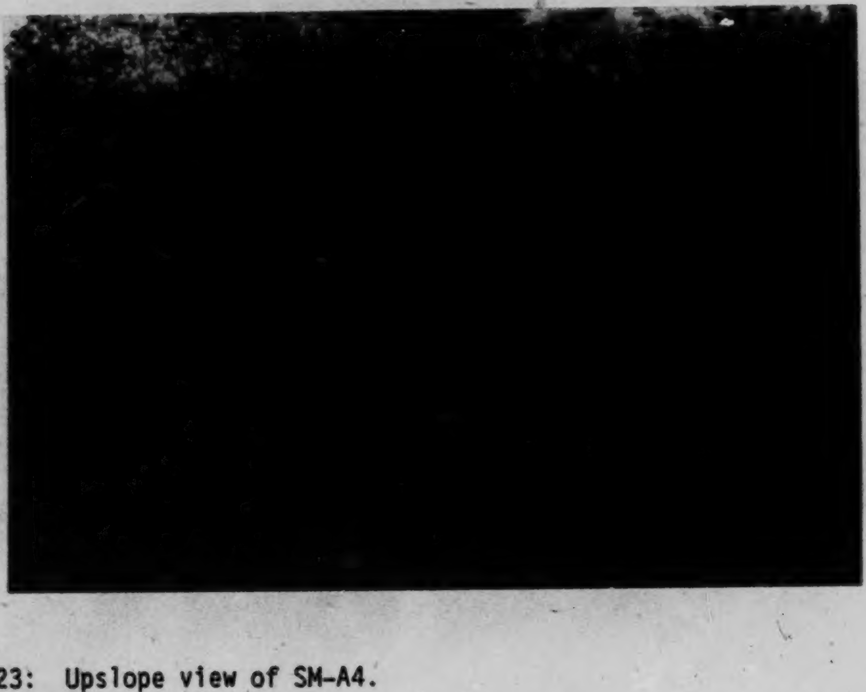

Figure 23: Upslope view of SM-A4.

Figure 24: Displaced overburden soils and fill exposed in a bank undercut by river erosion at the toe of SM-A4.

Slope movement SM-A2 is located at the upstream end of River Lot 15 (Table 4; Figures 16 and 19). A hand-level survey of the slope shows that the movement has a height of 24 m and an average inclination of 45 degrees (Table 5; Figures 18). The main scarp is bare of vegetation and slopes steeply down to 8 m above river level where colluvium gradually thickens to the toe of the movement At the mounds of displaced overburden soils have accumulated on a 8 m wide floodplain of the river (Figure 20). This material is being eroded during high river levels as indicated by a small undercut bank. Upstream and downstream from the toe of the SM-A2, seepage is discharging out across the floodplain (Figure 13).

The features of SM-A2 suggest a steeply inclined translational slide where blocks of till and overlying glaciolacustrine sediments have broken away from the main scarp and slid down the slope. During movement these blocks disintegrate to collect as displaced material in the toe area. EBA Engineering Consultants Ltd. (1973) noted that this movement originally occurred at mid slope during the summer of 1972 when the river level was abnormally high. Between 1972 and 1983 the main scarp of SM-A2 has only progressed upslope to the valley crest and has resulted in less than 1 m of regression.

Slope Movement SM-A4 is located in the middle of River Lot 15 approximately 90 m downstream of SM-A2 (Table 4; Figures 16 and 22). It has an average inclination of 34 degrees and a height of 23 m as determined from a hand-level survey (Table 5; Figure 21). The main scarp forms a 2 to 2.5 m high near vertical face which is bare of vegetation exposing glaciolacustrine silty clays. The slope below the main scarp is covered with displaced material which is vegetated by grasses and young trees (Figure 23). Concrete blocks and fill intermixed with displaced material occur on this slope and bulges into the river at the toe. An undercut cut bank 1 to 2 m high has been eroded into this bulge probably during the higher river levels (Figure 24). Eighteen metres above the toe a slickensided minor scarp approximately 4 m high has developed in the displaced material. Below this scarp there are several traverse tension cracks.

On the 1950 airphotos, SM-A4 appears as a narrow V-shaped gully likely formed from downslope run-off. Examination of subsequent airphotos up to 1972 shows that the gully progressively widened and the main scarp regressed 5 to 10 m into the uplands. Except for the minor scarp indicating a secondary movement in the displaced material and fill in the toe area, SM-A4 has remained dormant since 1972.

4.3.2 Slope Movement Area B

Slope movement Area B is at the north end of Fort Saskatchewan through River Lots 10 and 12 along the northwest side of the river valley (Figures 1 and 115; Appendix 1). In Area B the valley slopes rise 18 to 20 m above river level which is at an elevation of approximately 599 m. An island on the opposite side of the river diverts the main current against the toe of these slopes.

Four slope movements designated SM-B1 to SM-B4 occur along the slopes in Area B as mapped on Figures 25 and summarized in Table 4. A profile of slope movement SM-B1 is shown on Figure 26.

As delineated in borehole BH-B1, bedrock strata of the Belly River Formation comprises almost half the slopes with the overburden-bedrock contact at approximately 9 m above river level (Figure 26). The strata consists of silty to clayey shale with interbedded sandstone below river level. The shale contains slickensided zones 3 and 7 m above river level. In outcrop sections thin coal and ironstone beds less than 1 m in thickness are interbedded with the shale. In borehole BH-B1, 6.5 m of clay till directly overlies bedrock. However in outcrops on the face of slope movement SM-B4, approximately 350 m downstream up to 4 m of laminated to cross-bedded, silty sand occurs between the bedrock and the till. This sand is probably a deposit of Saskatchewan sand and gravel. The till is overlain by glaciolacustrine sediments consisting of 2.5 m of silty sand and 1.5 m of clay which forms the upland surface. Water levels in borehole BH-B1 averaged 6.33 m in depth or approximately 14 m above river level (Table 7; Figure 26). This water level appears to be excessively high in consideration of the groundwater table being drawn down towards the river valley as previously described in

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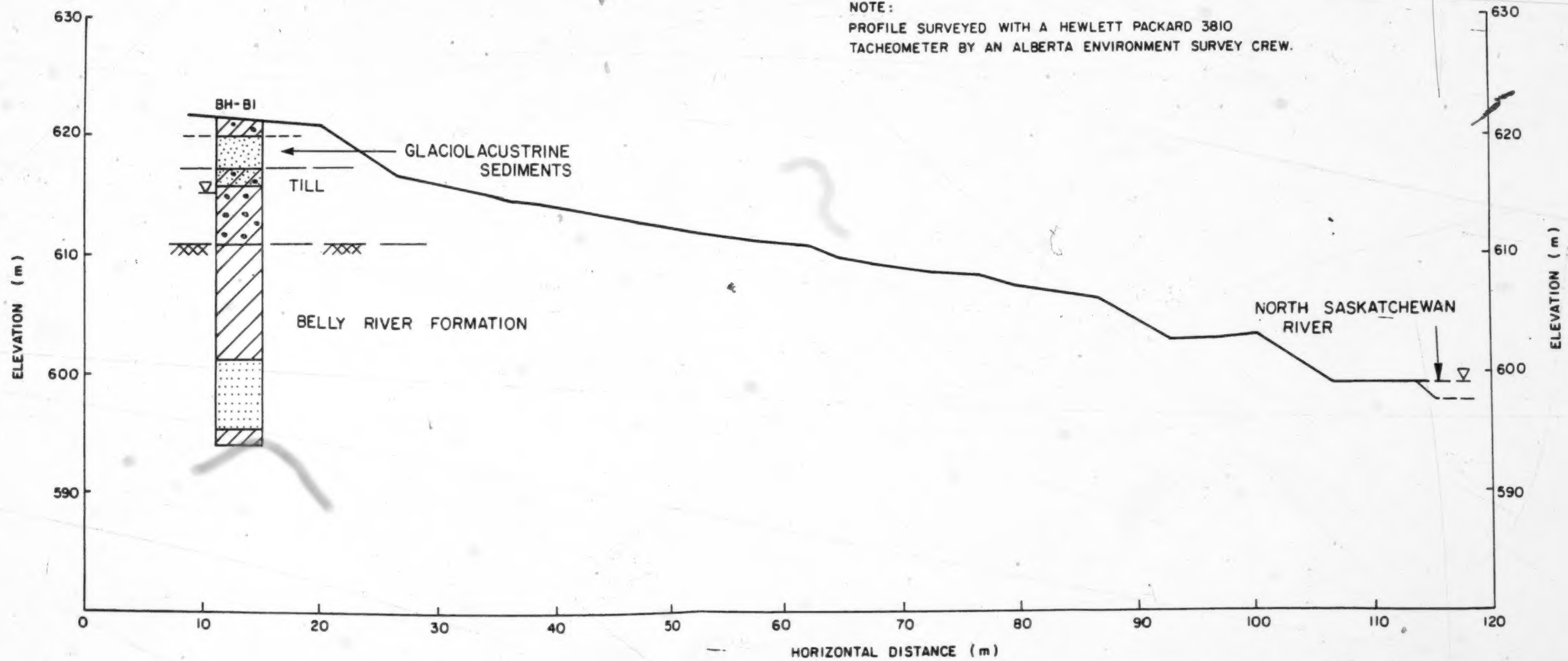
NORTH SASKATCHEWAN RIVER SLOPE STUDY

SLOPE MOVEMENTS SM-81 TO SM-84
RIVER LOTS 10 & 12 - FT. SASKATCHEWAN

SCALE 1:2000	SHEET 1 OF 1
DATE JUNE 1986	FIGURE 35

PD-280x420



NOTE:
PROFILE SURVEYED WITH A HEWLETT PACKARD 3810 TACHEOMETER BY AN ALBERTA ENVIRONMENT SURVEY CREW.

Alberta ENVIRONMENT DESIGN AND CONSTRUCTION DIVISION		NORTH SASKATCHEWAN. RIVER SLOPE STUDY
SUBMITTED	DESIGNED	PROFILE OF SLOPE MOVEMENT SM - B1
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Section 3.2 of Chapter 3. The high water level readings may be affected by perched water tables in the till. In addition an absence of seepage discharging near the contact of the Saskatchewan sand and gravel and underlying bedrock on adjacent slopes indicates the groundwater table is lower in the slopes.

Slope movement SM-B1 occurs at the upstream end of Area B in River Lot 12 of Fort Saskatchewan (Table 4; Figure 25). This movement has occurred in a slope which is approximately 20 m high and has an average inclination of 12 degrees as determined from a profile surveyed by Alberta Environment (Table 5; Figure 26). The main scarp is approximately 8 m high and is vegetated with grasses and young trees. It also has rounded margins along the crown and lateral flanks. The surface of the main body below the scarp is vegetated with mature trees and is characterized by a random assemblage of rounded ridges and depressions down to the toe area. At the toe a vertical bank 1 to 4 m high exposes reworked bedrock material. This bank is likely a result of erosion during high river levels but at the time of field work this bank was separated from the river by a 7 m wide floodplain.

With the dense vegetation and degraded geomorphic features of SM-B1 it is difficult to interpret the type of movement which it underwent. However, the reworked bedrock material exposed at the toe and the occurrence of a disrupted topography indicates that the rupture surface under the main body of the movement is at or below river level. Examination of the 1924 airphotos shows that SM-B1 has remained dormant for the past 60 years. The degraded main scarp and features of the main body along with the dense mature vegetation suggests an active-mature age class.

Slope movement SM-B3 is located approximately 250 m downstream of SM-B1 (Table 4; Figure 25). A profile constructed from a 1:25.000 topographic map (NTS 83H/11g) indicates that it is approximately 18 m high and has an average inclination of 22 degrees (Table 5). The geomorphic features of SM-B3 are similar to SM-B1 but sharper and less degraded. The main scarp is arcuate and has sharp to rounded margins. The steep smooth face of the scarp is vegetated with grasses and young trees. The surface topography of the main body is characterized by well-defined ridges and depressions amongst mature trees. In particular there is a slight depression along the base of the main scarp. Drainage down the front of the main body to the toe is largely controlled by the disrupted surface topography. Along most of the toe area reworked bedrock material is exposed along the face of a 1 to 3 m high bank eroded during higher river levels.

The arcuate main scarp with a depression along its base and the highly disrupted nature of the main body are criteria to suggest that SM-B3 underwent compound rotational-translational movement. The existence of reworked bedrock material and a disrupted surface in the toe area suggests that the rupture surface under the main body is at or below river level. Examination of older airphotos dating back to 1924 shows that SM-B3 has remained dormant over the past 60 years. Features such as the sharp to rounded margins of the main scarp with a cover of young vegetation on the well-defined disrupted surface of the main body and the controlled drainage down its surface suggest an inactive-young age class.

Slope Movement SM-B4 encompasses 430 m of slope at the downstream end of Area B (Table 4; Figure 25). A profile constructed from the 1:25000 topographic map (NTS 83H/11g) gives an approximate height of 19 m and an average inclination of 25 degrees (Table 5). The main scarp is formed by a near vertical face up to 5 m high which is bare of vegetation. The base of the scarp is marked by a cover of displaced material and partly disintegrated blocks of till and glaciolacustrine sediments. This cover thickens towards the toe of the slopes and in some places bulges into the river.

Translational downslope sliding of blocks which break off from the main scarp appears to be the primary movement occurring in SM-B4. A review of older airphotos dating back to 1924 shows that only minor changes in the slope configuration has occurred over the past 60 years. The steep main scarp and unvegetated condition of the slope suggests an active age class.

4.3.3 Slope Movement Area C

Slope Movement Area C encompasses the slopes along the northwest side of the river valley from a sharp meander in SW23-54-23-W4 downstream for approximately 2 km into SE26-54-23-W4 (Figures 1, 108, 110 and 111; Appendix 1). The slopes in the upstream end of Area C rise 38 to 40 m above river level which is at an elevation of approximately 602 m. The main current of the river flows against the toe of these slopes after flowing through the sharp southwest to northeast meander.

At the upstream end of Area C there are three slope movements designated SM-C1 to SM-C3 occur as mapped on Figures 27 and 35 and summarized in Table 4. A profile of slope movements SM-C1 is shown on Figure 28 while Figures 29 to 34 are photographs of this movement and its features. Figure 29 also provides a downstream view of slope movements SM-C2 and SM-C3. Photographs illustrating the features of SM-C3 are presented as Figures 36 and 37.

The slopes in which SM-C1 to SM-C3 occur are comprised mostly of bedrock with a thin veneer of overburden soils as encountered in borehole BH-C1 and mapped in outcrop sections (Figures 5 and 28). Interbedded sandstones and silty to clayey shales of the Belly River Formation extends to 32 m above river level. The clay shales range from being bentonitic to carbonaceous and contain thin layers of bentonite less than 100 mm in thickness and thin coal beds less than 0.25 m in thickness. This bedrock strata is overlain by up to 4 m of clay till which contains

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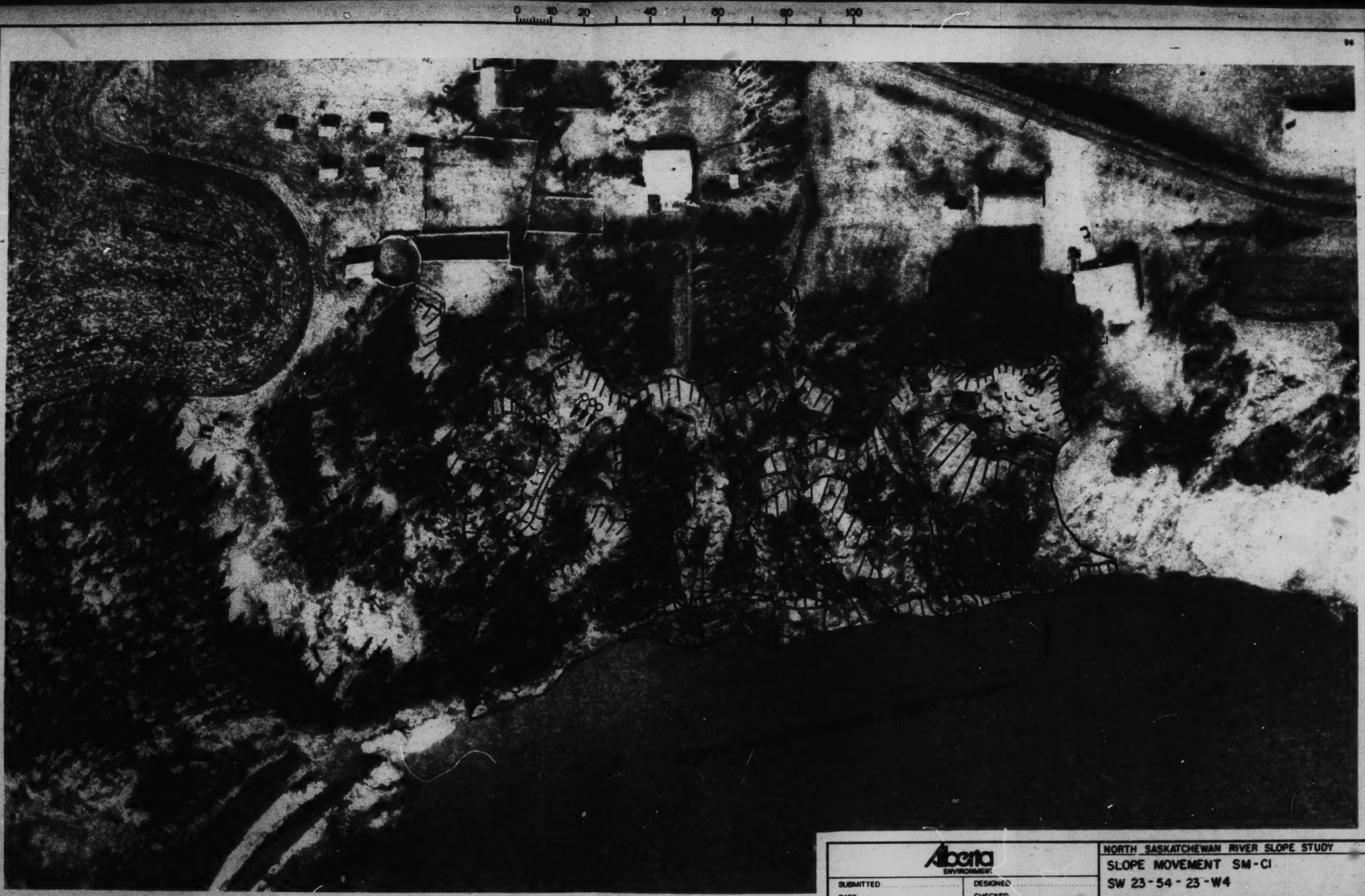

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

SLOPE MOVEMENT SM-CI

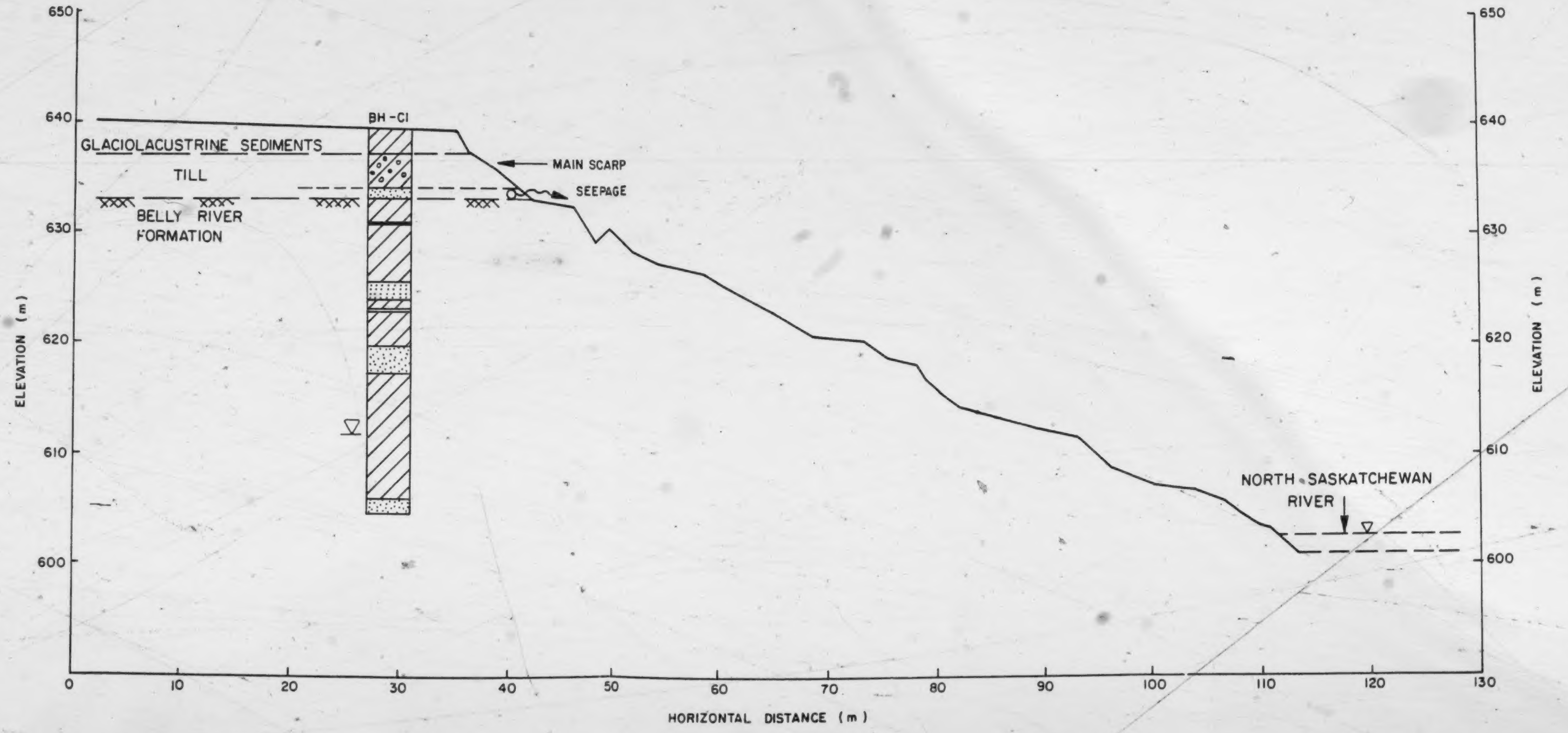
SW 23-54-23-W4

SCALE 1: 1000
DATE JUNE 1986

SHEET 1 OF 1
FIGURE 27

PS-280x430

NOTE:
PROFILE SURVEYED WITH A HEWLETT PACKARD 3810 TACHEOMETER BY AN ALBERTA ENVIRONMENT SURVEY CREW.



Alberta ENVIRONMENT	DESIGN AND CONSTRUCTION DIVISION	NORTH SASKATCHEWAN RIVER SLOPE PROFILE OF SLOPE MOVEMENT SM-C1
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Figure 29: Downstream view of slope movements SM-C1 and SM-C3.

Figure 30: Glaciolacustrine sediments overlying till exposed in the main scarp of SM-C1 below borehole BH-C1. Note darker seepage area at the base of the main scarp.

Figure 31: Rotated block of overburden soils exposed in the right flank of a seepage area in SM-C1, located approximately 40 m upstream of borehole BH-C1.

Figure 32: Rupture surface of the rotated block described in Figure 31.

Figure 33: Downslope view of a flow movement below the main scarp, in the middle of SM-Cl.

Figure 34: Low angle rupture surface in bedrock strata below a seepage area at the upstream end of SM-Cl.

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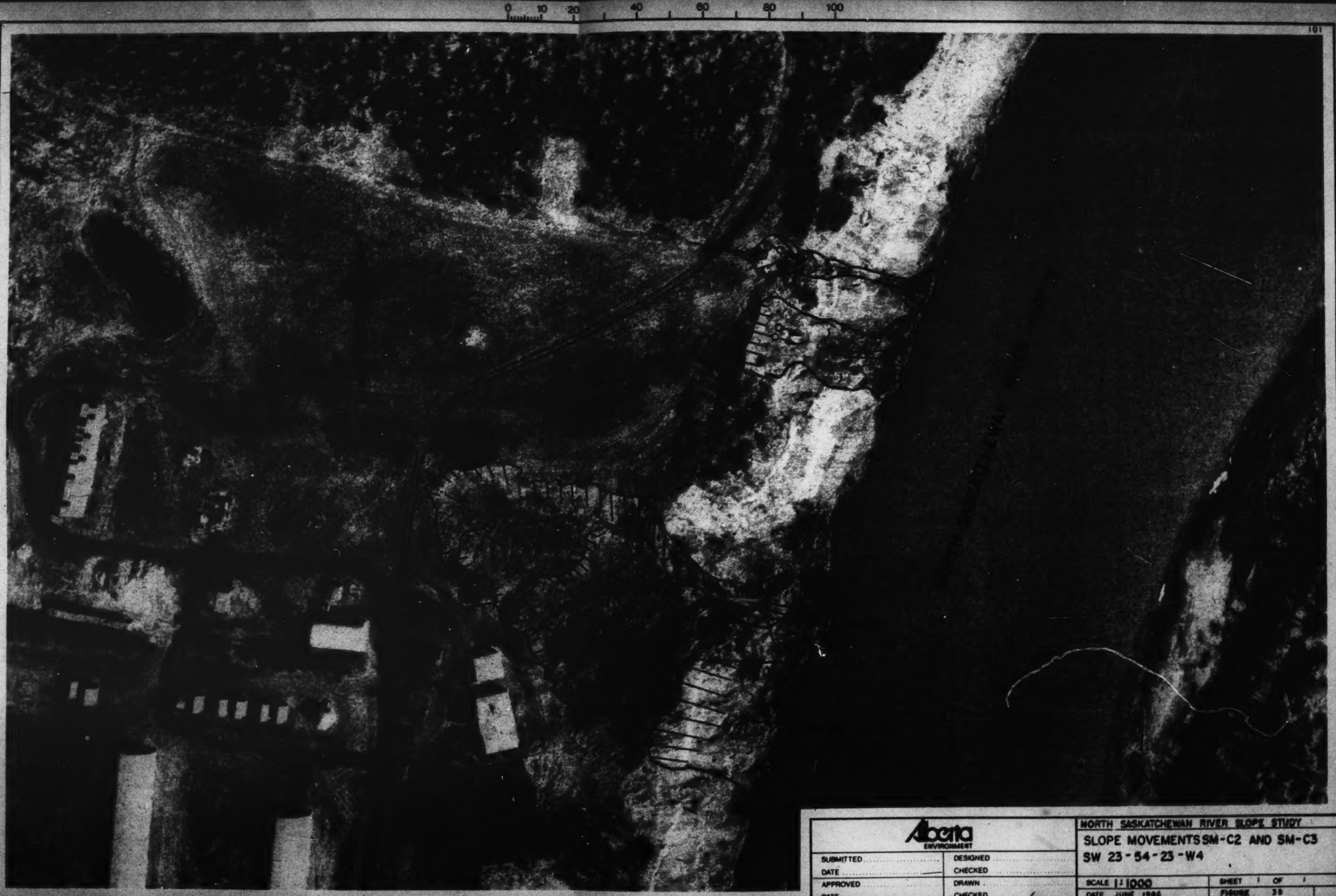

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

SLOPE MOVEMENTS SM-C2 AND SM-C3
SW 23 - 54 - 23 - W4

SCALE 1 : 1000
DATE JUNE 1986
SHEET 1 OF 1
FIGURE 39

Figure 36: Upslope view of slope movement SM-C3.

Figure 37: Displaced block along the right flank of SM-C3. Note the drain pipe protruding from the top of the block.

several sand lenses less than 1 m in thickness. Approximately 2.4 m of glaciolacustrine clay overlies the till and extends to the upland surface. Water levels in borehole BH-C1 averaged 27.58 in depth or approximately 4.4 m above river level (Figure 28; Table 7). This water level probably represents the groundwater table in consideration of the hydrogeological conditions described in Section 3.2 of Chapter 3. As Saskatchewan sand and gravel are absent in this area and till directly overlies bedrock there is probably only a minor contrast in permeability at their contact which doesn't significantly impede the downward movement of groundwater towards the river valley. However, a contract between the sand lenses and the surrounding till can result in the formation of perched water tables.

At the upstream end of Area C slope movement SM-C1 consists of a series of overlapping flow movements encompassing 250 m of slopes located below two farmsteads (Table 4; Figures 27 and 29). A profile surveyed at the downstream end of SM-C1 by Alberta Environment gives a slope height of 39 m and an average inclination of 17.5 degrees (Table 5; Figure 28). Across the top of SM-C1 the main scarp is 7.5 to 10 m high and is bare of vegetation (Figure 30). In several places seepage is discharging from perched water tables in sand lenses in the till near the base of the main scarp. Below the main scarp the flow movements are characterized by a series of minor scarps and areas of ponded water, within a saturated mixture of overburden soils and bedrock material (Figure 33 and 34). The slope is also dissected by V-shaped drainage gullies eroded by run-off from the uplands and seepage water. Near the top of SM-C1 these gullies are separated by densely vegetated, moved blocks of overburden soils which appear to have undergone rotational slumping (Figures 31 and 32). At the toe of SM-C1 the displaced material from the individual flow movements converge and bulge into the river. At several places river erosion has cut approximately a 1 m high bank into this material.

The flow movements in SM-C1 are directly related to the seepage and run-off from the uplands. Blocks of overburden soils slide off the main scarp as seepage washes out the sand lenses at the base creating a lack of underlying support. Saturation from seepage and run-off water breaks down the displaced block and the underlying surficial layer of bedrock. The intermixed soil and bedrock material flows downslope as a slurry. Movement is also likely aggravated by the removal of the displaced material at the toe by river erosion.

A review of the 1924 airphotos indicates that the SM-C1 began below a farmstead above the upstream end of the movement. Between 1962 and 1972 the house at the downstream end of SM-C1 was constructed and in this time flow movements began on the slopes below, expanding SM-C1 to its present configuration. Since initiation the flow movements have resulted in 5 to 10 m of valley crest regression over the past 60 years. Further regression can be expected as the movement is active particularly in the downstream end.

Approximately 300 m downstream from SM-C1 there is another flow movement designated SM-C3 (Figures 29 and 35). This movement is associated with a large gully eroded approximately 60 m back from the valley crest into the uplands. The main scarp around the lateral flanks of SM-C3 is 5 to 8 m high and is vegetated with grasses and the odd young tree (Figure 36). Below the main scarp there are moved blocks of overburden soils which have undergone downward and slight rotational slumping (Figure 37). A broken drain pipe protrudes from one of these moved blocks on the right flank of the gully. Below these blocks saturated bedrock material forms a flow movement out the narrow mouth of the gully and down into a fan shaped bulge into the river.

The present source of water for this gully erosion is provided by seepage discharging at the base of the main scarp along the right flank directly below a house. In addition, from the head of the gully there appears to be an intermittent run-off channel connected to a small slough approximately 80 m back in the uplands. On the 1924 airphotos, SM-C3 was a small drainage gully eroded approximately 15 m into the uplands with a distinct channel back to this slough and since then the head of the gully has regressed an additional 35 to 45 m . Between 1950 and 1962 the gully enlarged rapidly in comparison to the amount of erosion which had occurred between 1924 and 1950. Also, between 1950 and 1962 a house was constructed next to the right flank of the gully which has now encroached to within 5 m of a garage located beside the house.

On the river valley slopes 80 to 100 m downstream from SM-C3 there are two other smaller flow movements (Figure 35). The one closest to SM-C3 is caused by seepage discharging from a 0.6 to 0.7 m thick sand lens located approximately 6 m below the valley crest within the till. Approximately 20 m further downstream there is a steep V-shaped gully with a flow of saturated bedrock debris forming a bulge into the river at the toe. The source of water for this gully erosion is intermittent run-off from the uplands. This gully began eroding between 1962 and 1972 as evidenced by the older airphotos. Since then the head of the gully has regressed 5 to 10 m into the uplands and has widened 5 m at the top of the slope. Scrap metal and other garbage has been dumped in the upper part of the gully, probably in an attempt to inhibit further erosion as the landowners occupy the house adjacent to SM-C3.

Towards the downstream end of Slope Movement Area C the valley slopes rise 29 to 36 m above the river which is at an elevation of approximately 601 m. Eight slope movements designated SM-C4 to SM-C11 occur along the northeast side of the river through this reach from NW23 to SE26-54-23-W4 as mapped on Figures 38, 41, 45 and 48 and summarized in Table 4. Profiles of slope movements SM-C4, SM-C5, SM-C6 and SM-C7 are shown on Figures 39, 42, 46 and 49 respectively. Photographs of slope movements SM-C4 to SM-C9 and their features [illegible] presented as Figures 40, 43, 44, 47 and 50 to 54.

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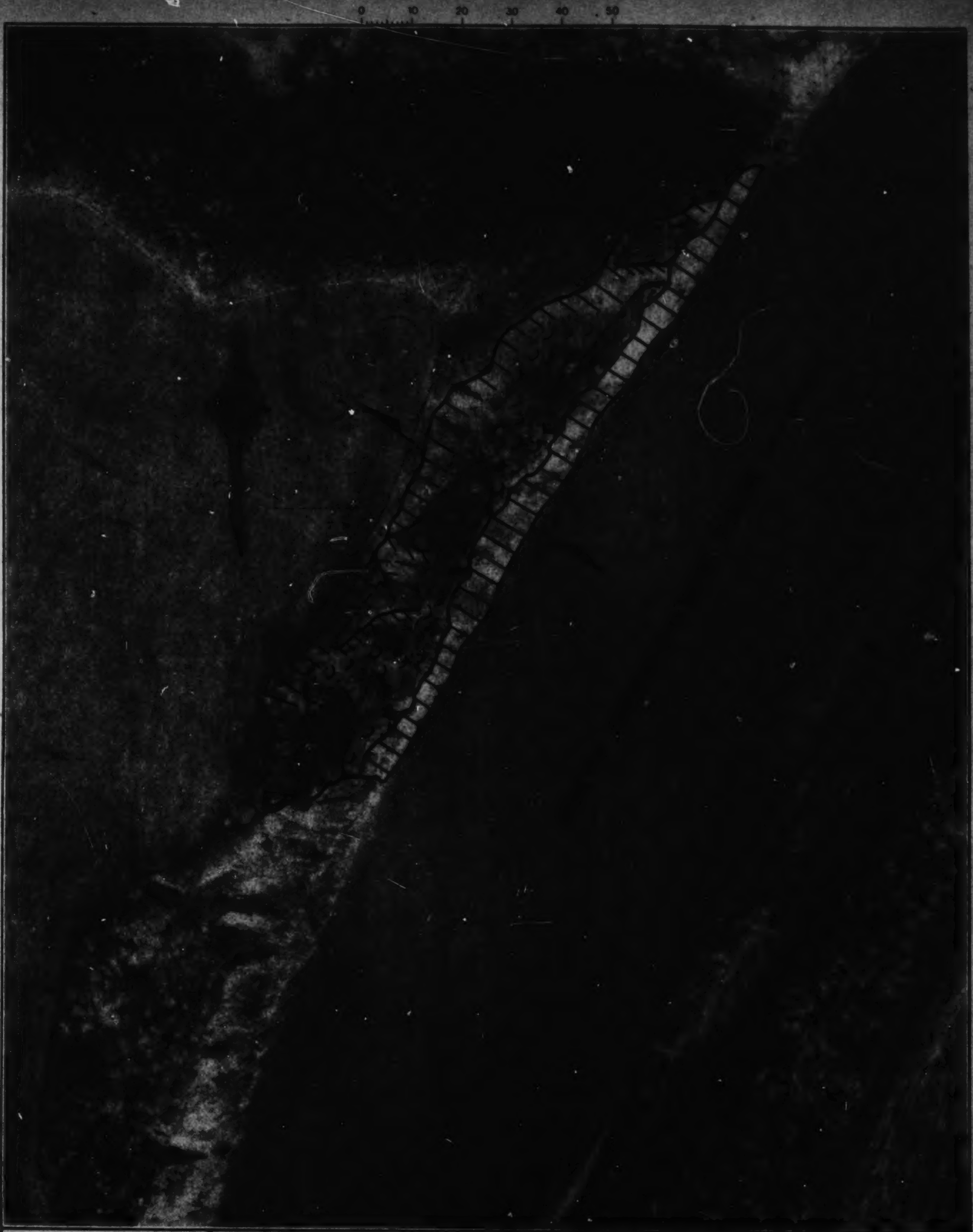

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

SLOPE MOVEMENT SM-C4
SW 23-54-23-W4

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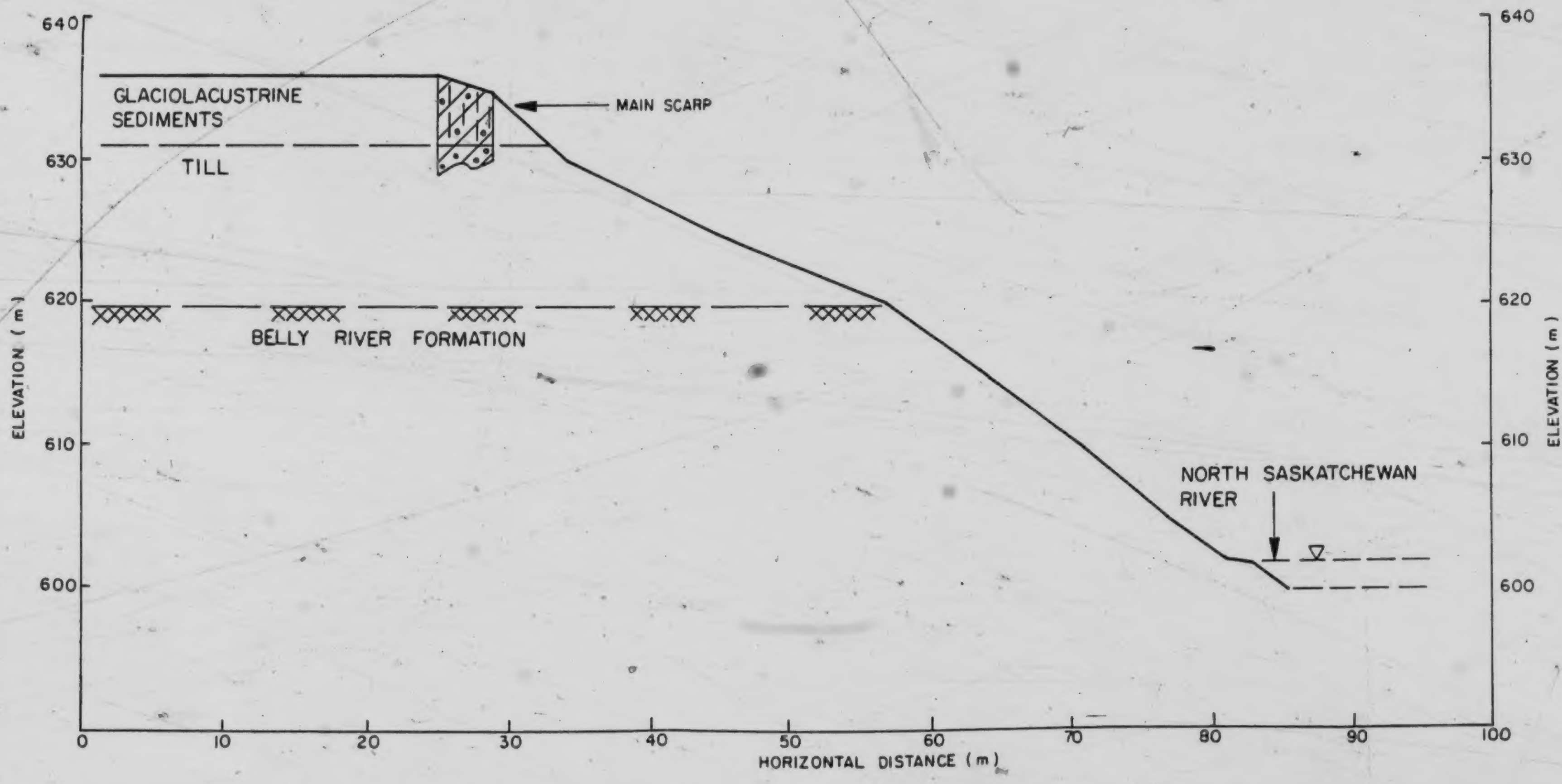
DATE JUNE 1986

SHEET 1 OF 1
FIGURE 38

NOTES:
1. STRATIGRAPHY MAPPED FROM OUTCROP SECTIONS IN MAIN SCARP AND LOWER SLOPE.
2. PROFILE CONSTRUCTED FROM 1:5000 CONTOUR MAP (CADASTRAL NUMBER 949 + 48)


640
630
620
610
600
GLACIOLACUSTRINE SEDIMENTS
TILL
MAIN SCARP
BELLY RIVER FORMATION
NORTH SASKATCHEWAN RIVER
ELEVATION (m)
0
10
20
30
40
50
60
70
80
90
100
HORIZONTAL DISTANCE (m)

Alberta ENVIRONMENT DESIGN AND CONSTRUCTION DIVISION		NORTH SASKATCHEWAN RIVER SLOPE STUDY PROFILE OF SLOPE MOVEMENT SM - C4
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Figure 40: Downstream view of slope movement SM-C4 shown at the right hand side of the photo. Note the lower face of insitu bedrock strata above river level.

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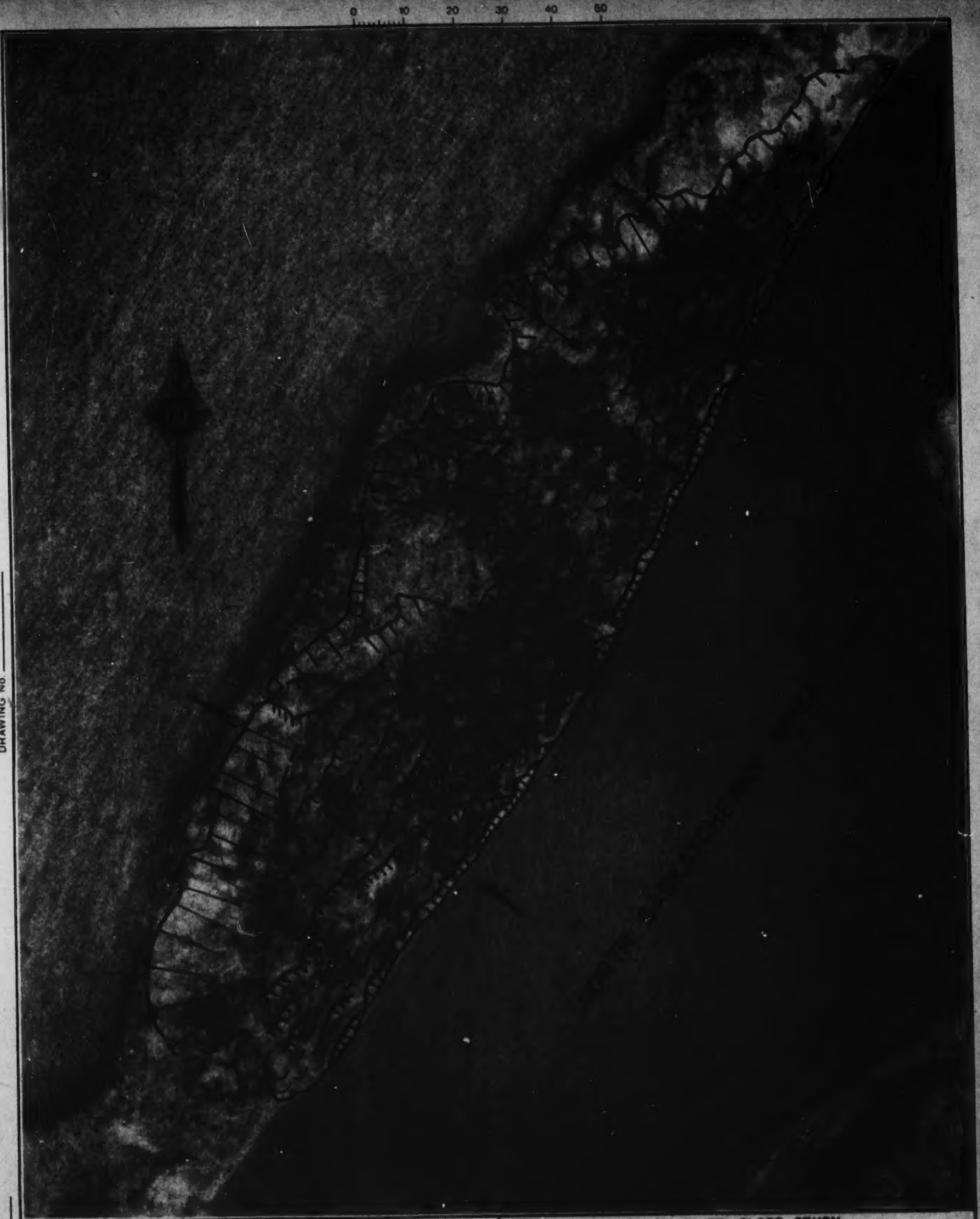

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

SLOPE MOVEMENT SM - C5
NW 23 - 53 - 23 - W4

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SCALE 1:2000	SHEET 1 OF 1
DATE JUNE 1986	FIGURE 41

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NOTE:
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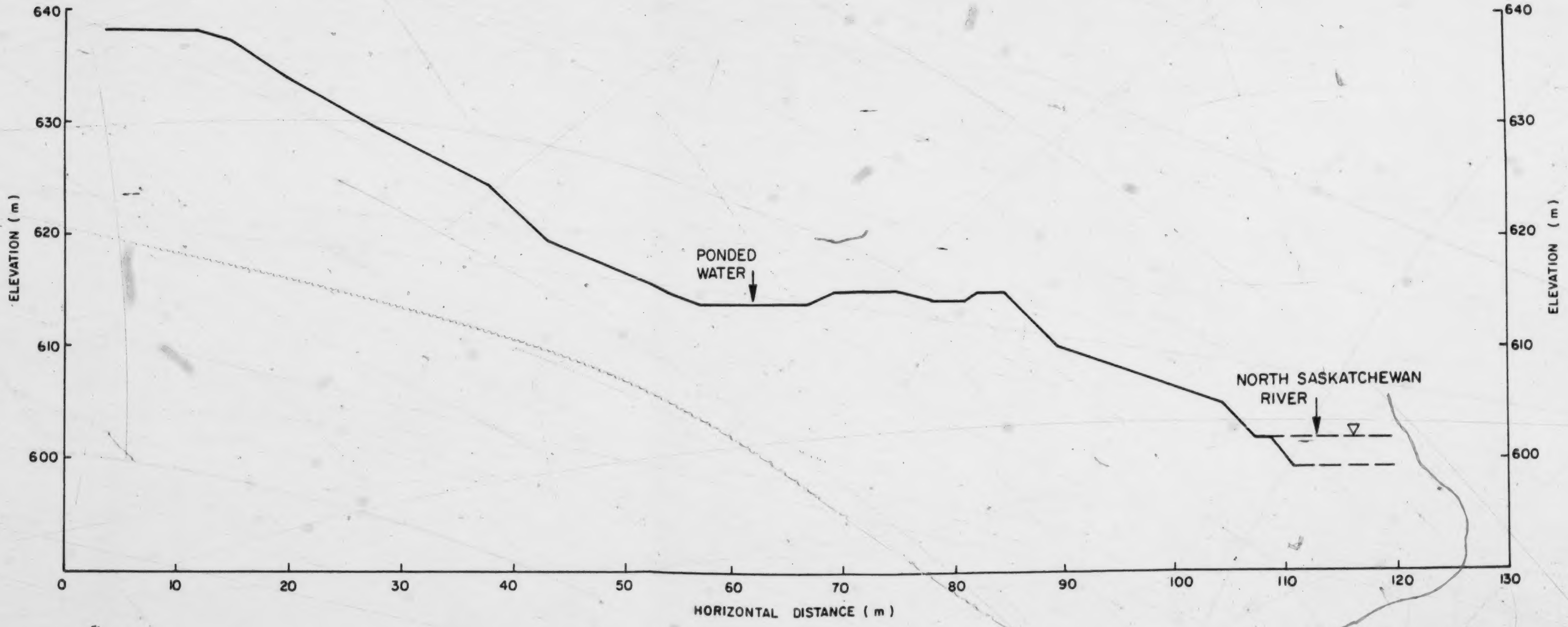
MAP (CADASTRAL NUMBER 949+48)



Alberta ENVIRONMENT DESIGN AND CONSTRUCTION DIVISION		NORTH SASKATCHEWAN RIVER SLOPE STUDY
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Figure 43: Upstream view of slope movement SM-C5. Note densely treed displaced material bulging into the North Saskatchewan River.

Figure 44: Secondary slides and falls occurring in the displaced material at the toe of SM-C5 as a result of river erosion.

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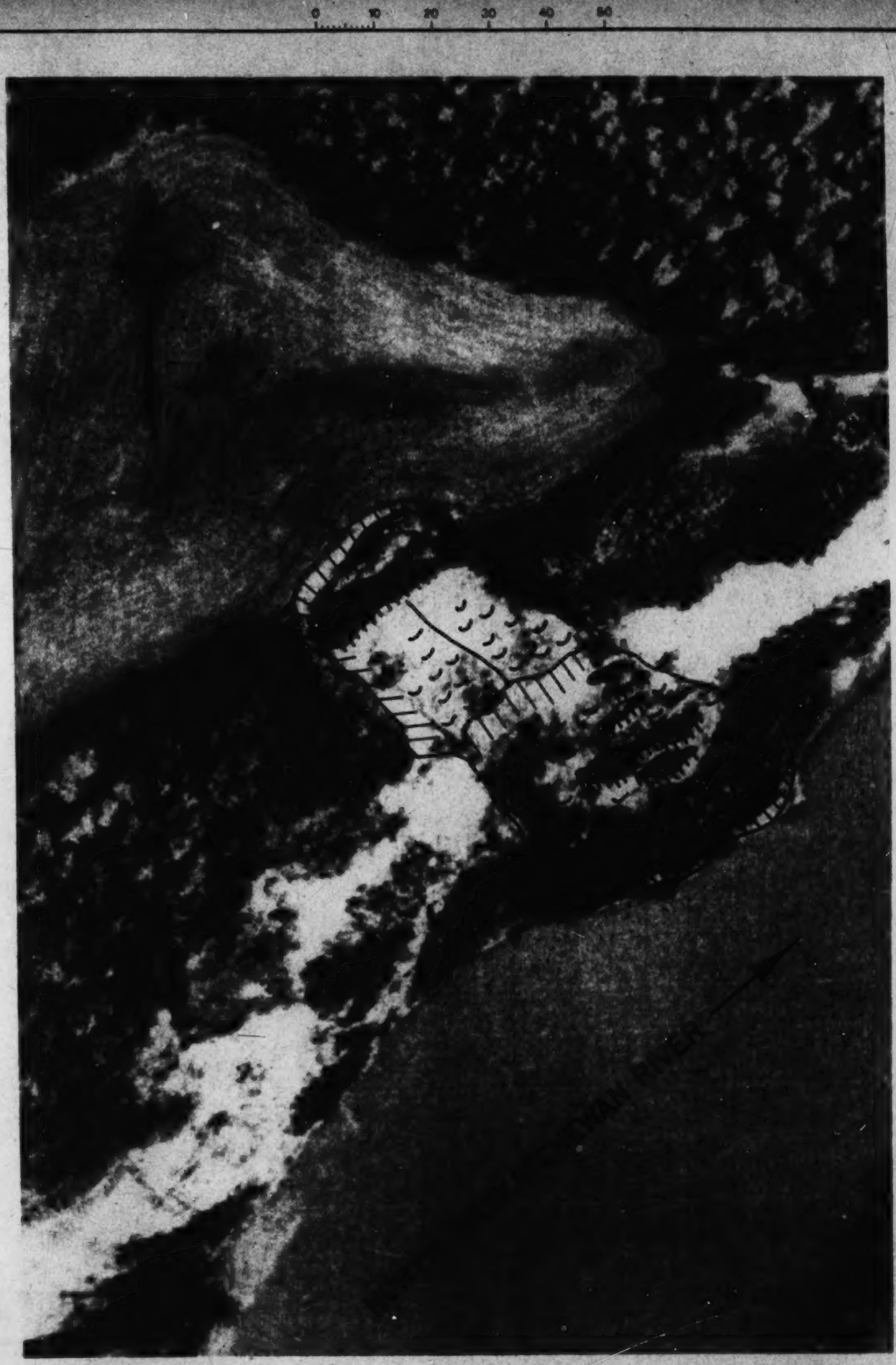

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

SLOPE MOVEMENT SM - C6
NE 4-54-23 - W4

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DATE	CHECKED	DATE JUNE 1986	FIGURE 45

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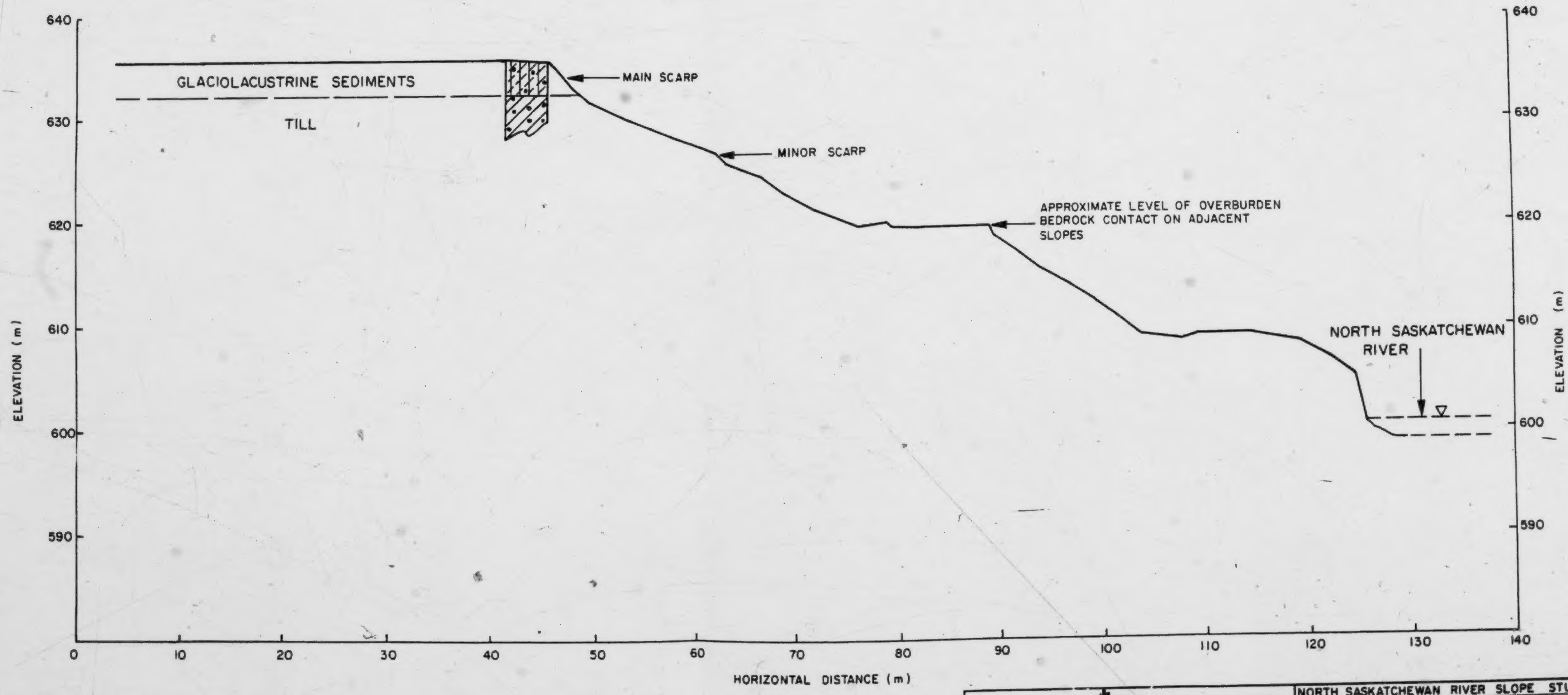
NOTES:
1. STRATGRAPHY MAPPED FROM OUTCROP SECTION IN MAIN SCRAP.
2. PROFILE CONSTRUCTED FROM HAND-LEVEL SURVEY.



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DATE JUNE 1986

FIGURE 46

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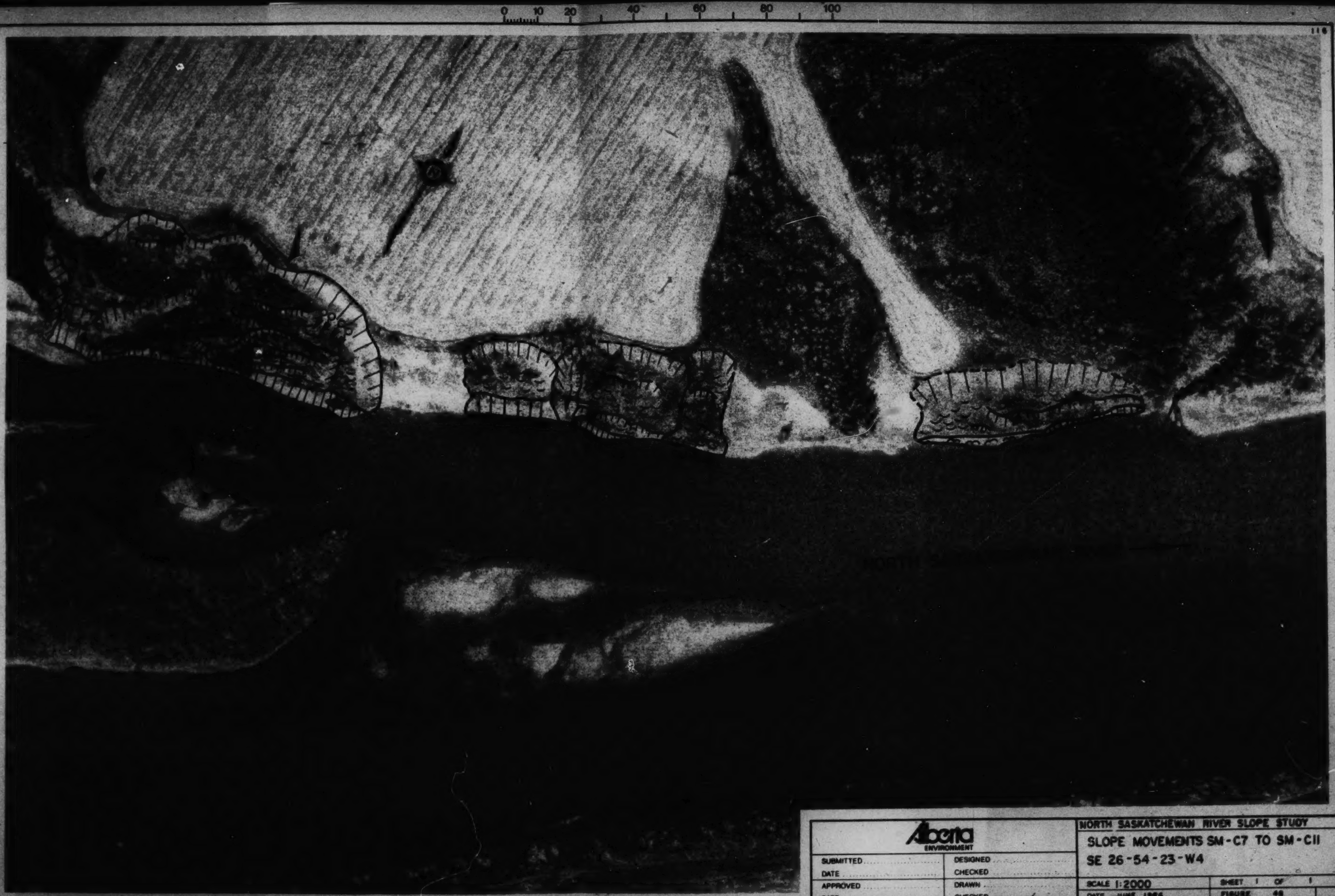
Figure 47: Upslope view of slope movement SM-C6.



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NORTH SASKATCHEWAN RIVER SLOPE STUDY

SLOPE MOVEMENTS SM-C7 TO SM-C11
SE 26-54-23-W4

SCALE 1:2000
DATE JUNE 1986

SHEET 1 OF 1
FIGURE 48

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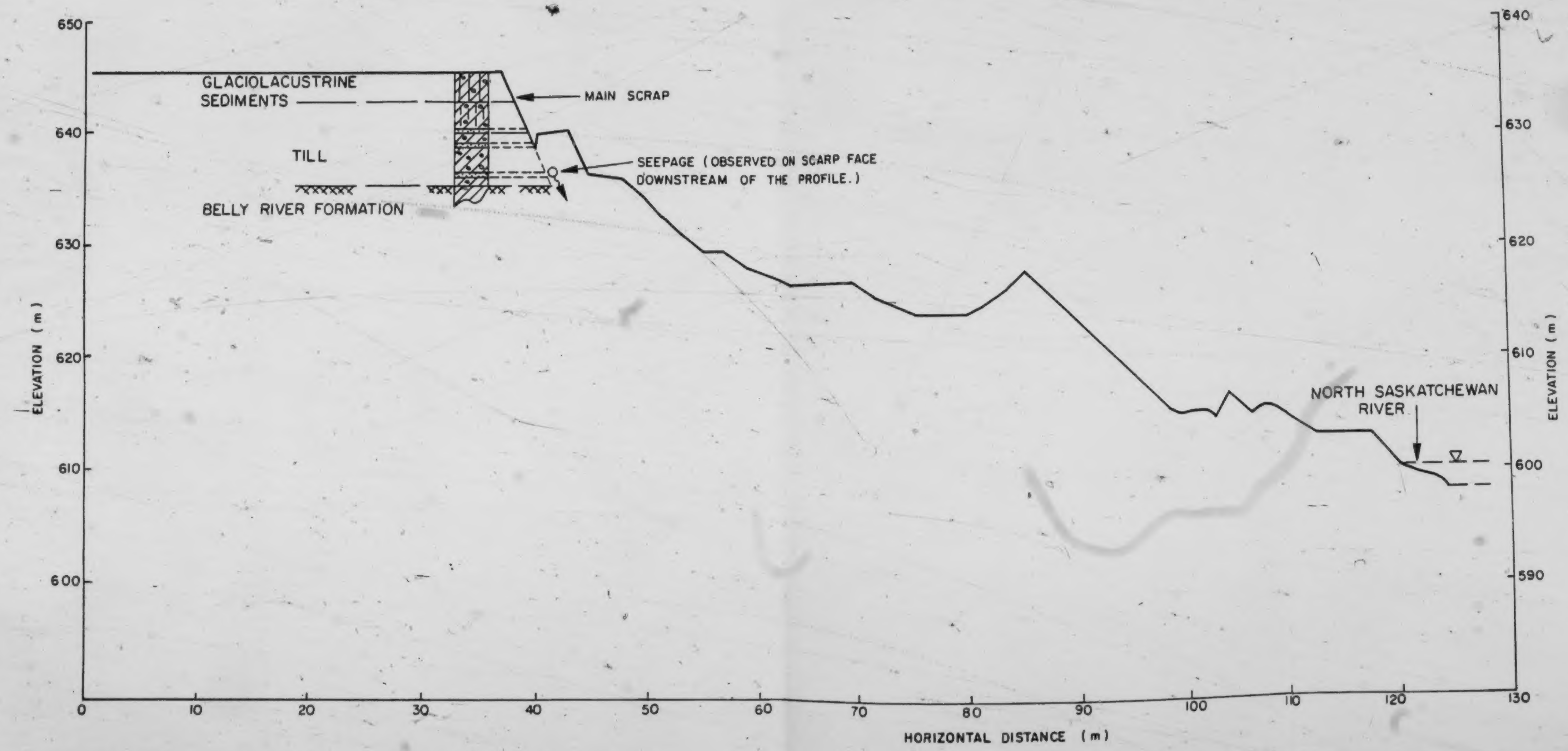
NOTES :

1. STRATIGRAPHY MAPPED FROM OUTCROP SECTION IN MAIN SCARP.
2. PROFILE CONSTRUCTED FROM HAND-LEVEL SURVEY.



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NORTH SASKATCHEWAN RIVER SLOPE STUDY

PROFILE OF SLOPE MOVEMENT SM - C7

SCALE AS SHOWN	SHEET 1 OF 1
DATE JUNE 1986	FIGURE 49

P3-280x430

Figure 50: Upslope view of the main scarp of slope movement SM-C7.

Figure 51: Clay coated, slickensided rupture surface in glaciolacustrine silts and clays on the main scarp of SM-C7.

Figure 52: Displaced overburden soils and bedrock material exposed in a bank undercut by river erosion at the toe of SM-C7

Figure 53: Upstream view of slope movements SM-C9 (foreground) and SM-C8 separated by a ridge between their lateral flanks.

Figure 54: Downstream view of the toe area below SM-C8 and SM-C9. Note the lower face of insitu bedrock strata below SM-C8 (foreground) in contrast to the bulge of displaced material at the toe of SM-C9.

Outcrop sections in the main scarp of SM-C7 shows that clayey shale strata of the Belly River Formation extend up to 26 m above river level and is overlain by 10 to 11 m of overburden soils (Figure 39). The sequence of overburden soils begins with 6 to 7 m of clay till which contains lenses of silty to gravelly sand up to 0.5 m in thickness. The till is overlain by up to 4 m of glaciolacustrine silty clays which extend to the upland surface.

The slope movements in the downstream end of Area C fall into two groups based on their probable type of movement and position of the rupture surface. The first group includes SM-C4, SM-C6 and SM-C8. Slope movements SM-C4 and SM-C6 occur in NW23-54-23-W4 while SM-C8 is in SE26-54-23-W4 (Table 4; Figures 38, 41 and 48). Of these SM-C6 is considered to be representative. It has a height of approximately 36 m and an average inclination of 21 degrees as determined from a hand-level profile (Table 5; Figure 46). The outline of the main scarp is arcuate. Its steep face is 4 to 5 m high and is bare of vegetation (Figures 10 and 49). Below the main scarp there are rotated blocks within a highly disrupted mass of displaced overburden soils. Halfway down the movement, at approximately 20 m above river level, the inclination of the surface of the displaced material steepens to an average of 35 degrees. This steepening approximately coincides with the level of the overburden-bedrock contact on adjacent unmoved slopes. The surface of this steeper slope is disrupted by minor scarps in the displaced material and slightly rotated blocks of overburden soils which form a rounded bulge into the river at the toe.

The highly distorted nature and the rotated blocks are criteria to indicate a compound rotational-translational movement. The rupture surface of SM-C6 likely extends down from the main scarp to a roughly horizontal position along the overburden-bedrock contact. This is evidenced by the displaced material being comprised entirely of overburden soils and the abrupt change to a steeper inclination at a level approximately coinciding with the overburden-bedrock contact. Examination of the 1962 and 1972 airphotos reveals that SM-C6 occurred between 15 and 20 years ago and has since resulted in 10 to 15 m of valley crest regression.

A profile of slope movement SM-C4 constructed from a 1:5000 contour map (Cadastral Number 949+48) shows that it has a height of 35 m and an average inclination of 27 degrees (Table 5; Figure 39). Similarily slope movement SM-C8 has a height of 33 m and an average inclination of 27 degrees. At the toe of SM-C4 and SM-C8 there is a steep, unvegetated slope exposing insitu bedrock strata up to 25 m above river level (Figures 40 and 54). Displaced overburden soils are exposed in the upper 5 m of these slopes. In both movements the main body above has a dense cover of young to mature trees on a surface disrupted by minor scarps and rotated blocks (Figures 40 and 53). The main scarp of SM-C4 is linear to slightly arcuate while the main scarp of SM-C8 is arcuate. Both scarps have sharp to rounded margins along the crown and lateral flanks. The scarp faces are steep and sparsely vegetated with grasses and young trees.

Similar features between SM-C4, SM-C8 and SM-C6 include the arcuate shape of the main scarps and the highly disrupted nature of the main bodies to indicate a compound rotational-translational movement. As well, overburden soils comprise the displaced material above their rupture surfaces which likely extend down from the main scarp and along the overburden-bedrock contact.

Examination of the older airphotos shows that SM-C4 and SM-C8 occurred prior to 1924 and have remained dormant over the past 60 years. Their well-defined main scarps and disrupted features below covered with a young to mature vegetation suggests an inactive age class for both SM-C4 and SM-C8.

The second group of slope movements in the downstream end of Area C includes SM-C5, SM-C7 and SM-C9. Slope movement SM-C5 is located in NW23-54-23-4 while SM-C7 and SM-C9 are located SE26-54-53-W4 (Table 4; Figures 41 and 48). Slope movement SM-C7 is a typical example of this group. A hand-level profile of this movement shows that it has a height of approximately 36 m and an average inclination of 18 degrees (Table 5; Figure 49). The main scarp is slightly arcuate and has sharp margins along the crown and lateral flanks. The face of the scarp is steep, varies in height from 5 to 10 m and is bare of vegetation exposing (Figure 50). A thin layer of slickensided clay, coats glaciolacustrine silts and clays exposed on the face of the main scarp (Figure 51). On the downstream side of the main scarp, seepage is occurring from a perched water table in sand lenses within the till. In the middle of SM-C7, at the base of the scarp there are several downward rotated blocks of overburden soils. Below these blocks the main body of the movement is a sparsely vegetated, distorted mass of intermixed overburden soils and bedrock material disrupted by minor scarps, transverse ridges and tension cracks. There are also several blocks with a backwards tilt having backslope inclinations of 35 to 60 degrees (Figure 41). At the toe of SM-C7 the displaced material bulges into the river. An island opposite SM-C7 diverts the main current of the river against the toe of the movement resulting in intense erosion which has cut a steep 1 to 3 m high bank into the displaced material (Photo 53).

The slightly arcuate, steep main scarp and the highly disrupted surface of the main body with several rotated blocks indicates that SM-C7 underwent compound rotational-translational movement. The rupture surface is at or below river level in the bedrock strata as indicated by the displaced material exposed in the undercut bank along the toe. The primary cause of this movement is suspected as being intense river erosion at the toe which may have initiated the development of a rupture surface along a weak plane in the bedrock. In addition, a build-up of seepage pressures in the sand lenses behind the main scarp area may have contributed to this movement.

Examination of older airphotos indicates that SM-C7 occurred as a series of movements. In 1924, movement of the upstream side of SM-C7 had already occurred while movement of the downstream side began between 1962 and 1972 and has resulted in 3 m to 5 m of valley crest regression. This side of SM-C7 is still active as ongoing river erosion continues to unload the toe.

Slope movements SM-C5 and SM-C9 are similar to SM-C7 in that they have linear to slightly arcuate, main scarps, highly disrupted main bodies and displaced overburden soils and bedrock material exposed in undercut banks along their toes (Table 4; Figures 41 and 48). As indicated by a profile constructed from a 1:5000 contour map (Cadastral Number 949+48) slope movement SM-C5 has a height of 37 m and an average inclination of 20 degrees (Table 5; Figures 42). Its main scarp has sharp to rounded margins along the crown and lateral flanks. The scarp face is steep and sparsely vegetated with grasses and young trees. The disrupted features of the densely treed surface of the main body include well-defined minor scarps, rotated blocks and undra[illegible]ed depressions and tension cracks. In particular there is a slight depression along the base of the main scarp formed by a backslope surface of the main body. Downslope drainage across the main body is partly controlled by the disrupted features. At the toe, secondary slides and falls are being caused by active river erosion (Figure 44). An inactive-young age classification is assigned to SM-C5 based on these characteristics.

A profile constructed from a 1:5000 contour map (Cadastral Number 949+48) shows that slope movement SM-C9 has a height of 31 m and an average inclination of 26 degrees (Table 5). Its main scarp has rounded margins along the crown and lateral flanks. The scarp face is steep and densely vegetated with shrubs and young trees. The surface of the main body is also densely vegetated with young trees and has a rounded hummocky topography. Displaced overburden soils and bedrock material bulges into the river at the toe and is exposed in undercut banks up to 1 m high along the upstream side of the movement. The degraded features of SM-C4 indicate an inactive-mature age class.

4.3.4 Slope Movement Area D

Slope Movement Area D is situated along the outside of a broad meander stretching from NE13 to NW3-54-23-W4 (Figure 1 and 106; Appendix 1). Through this meander the river is at an elevation of approximately 606 m and changes flow direction from northwest to east. The main current of the river flows along the toes of the valley slopes which are 30 to 35 m high. In Area D, 10 slope movements designated SM-D1 to SM-D10 occur along the outside of the meander as mapped on Figures 55, 59 and 65 and summarized in Table 4. Profiles of slope movements SM-D1, SM-D5, SM-D7 and SM-D9 are shown on Figures 56, 60, 64 and 68 respectively. Photographs of slope movements SM-D1, SM-D3, SM-D5, SM-D6 and SM-D8 are presented as Figures 57, 58, 61 to 63, 66 and 67.

As mapped in an outcrop section on the right flank of slope movement SM-D6 the slopes in Area D are comprised of overburden soils with bedrock below river level (Figure 64). Saskatchewan sand and gravel extends to

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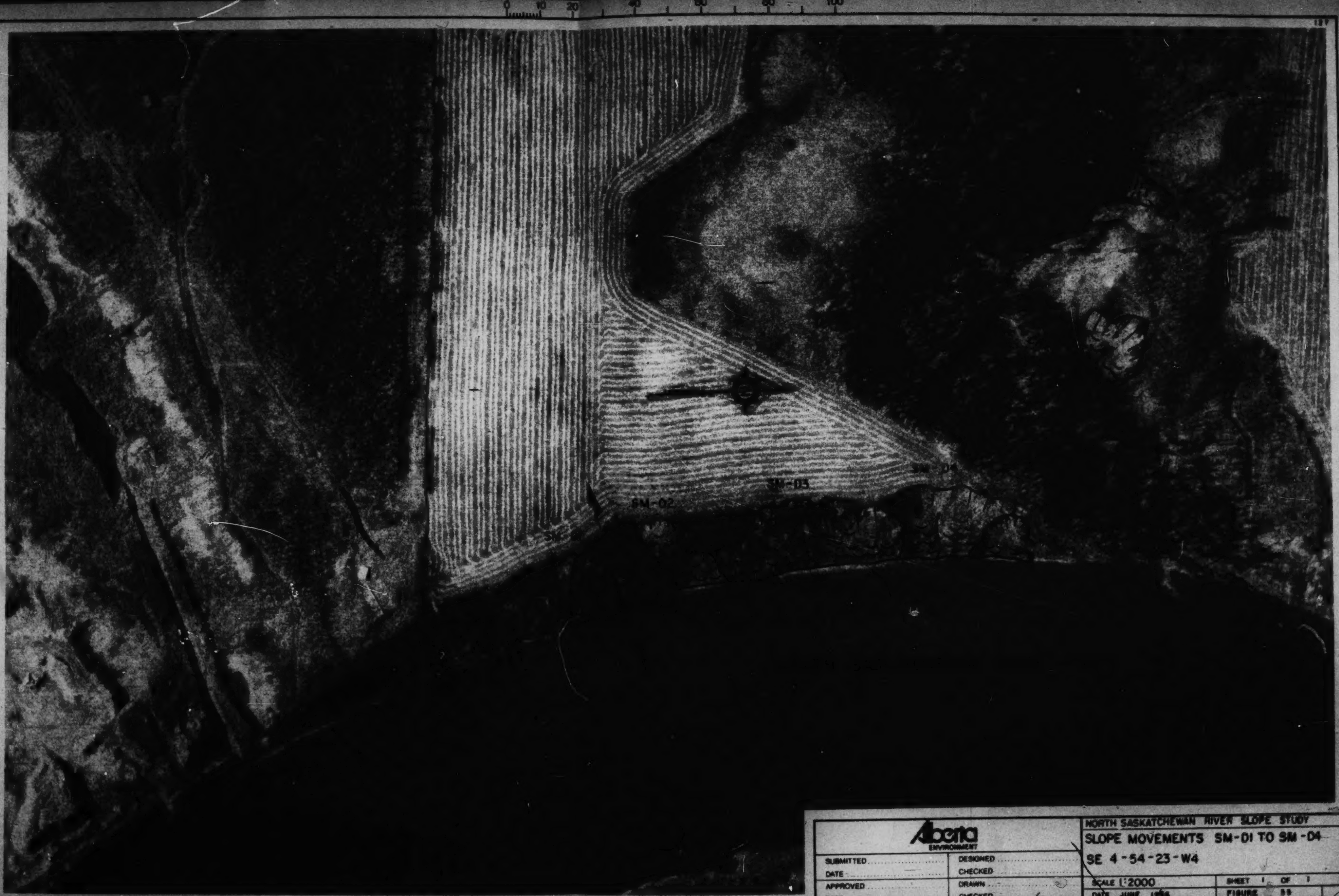
0
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80
100
SM-01
SM-02
SM-03
SM-04

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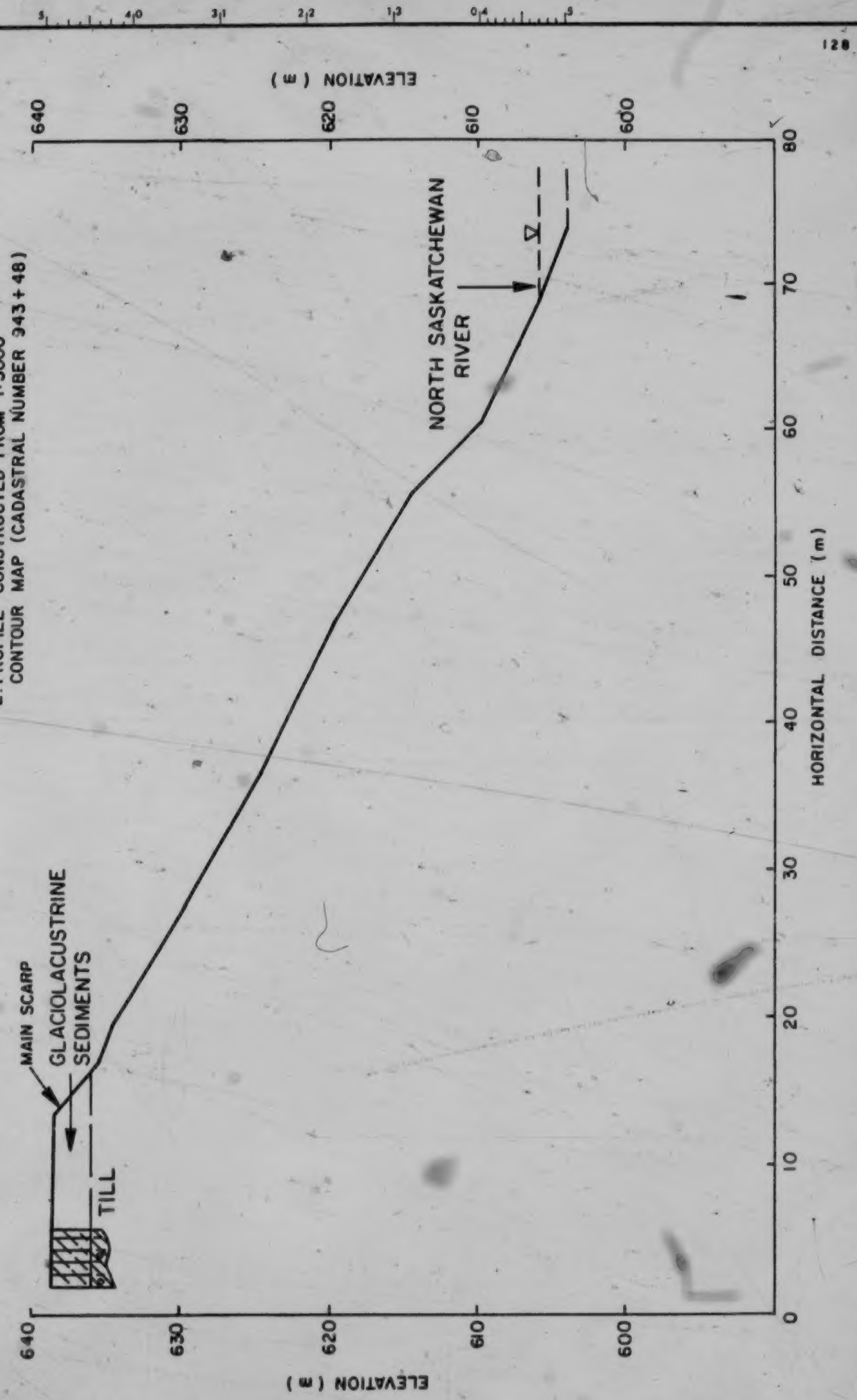
NORTH SASKATCHEWAN RIVER SLOPE STUDY

SLOPE MOVEMENTS SM-01 TO SM-04

SE 4-54-23-W4

SCALE 1:2000
DATE JUNE 1986

SHEET 1 OF 1
FIGURE 55



NOTES:

1. STRATIGRAPHY MAPPED FROM OUTCROP SECTION IN MAIN SCARP
2. PROFILE CONSTRUCTED FROM 1:5000 CONTOUR MAP (CADASTRAL NUMBER 943+48)

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

PROFILE OF SLOPE MOVEMENT SM-01

SCALE AS SHOWN	SHEET 1 OF 1
DATE JUNE 1986	FIGURE 56

Figure 57: Curvilinear fractures in overburden soils exposed in the left flank of slope movement SM-D1.

Figure 58: Upstream view of a displaced block of overburden soils below the main scarp of slope movement SM-D3.

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NORTH SASKATCHEWAN RIVER SLOPE STUDY
SLOPE MOVEMENTS SM-05 TO SM-07
SE 4 TO NW 3-54-23-W4

SCALE 1:2000
DATE JUNE 1986
SHEET 1 OF 1
FIGURE 59

MICROFILM DATE

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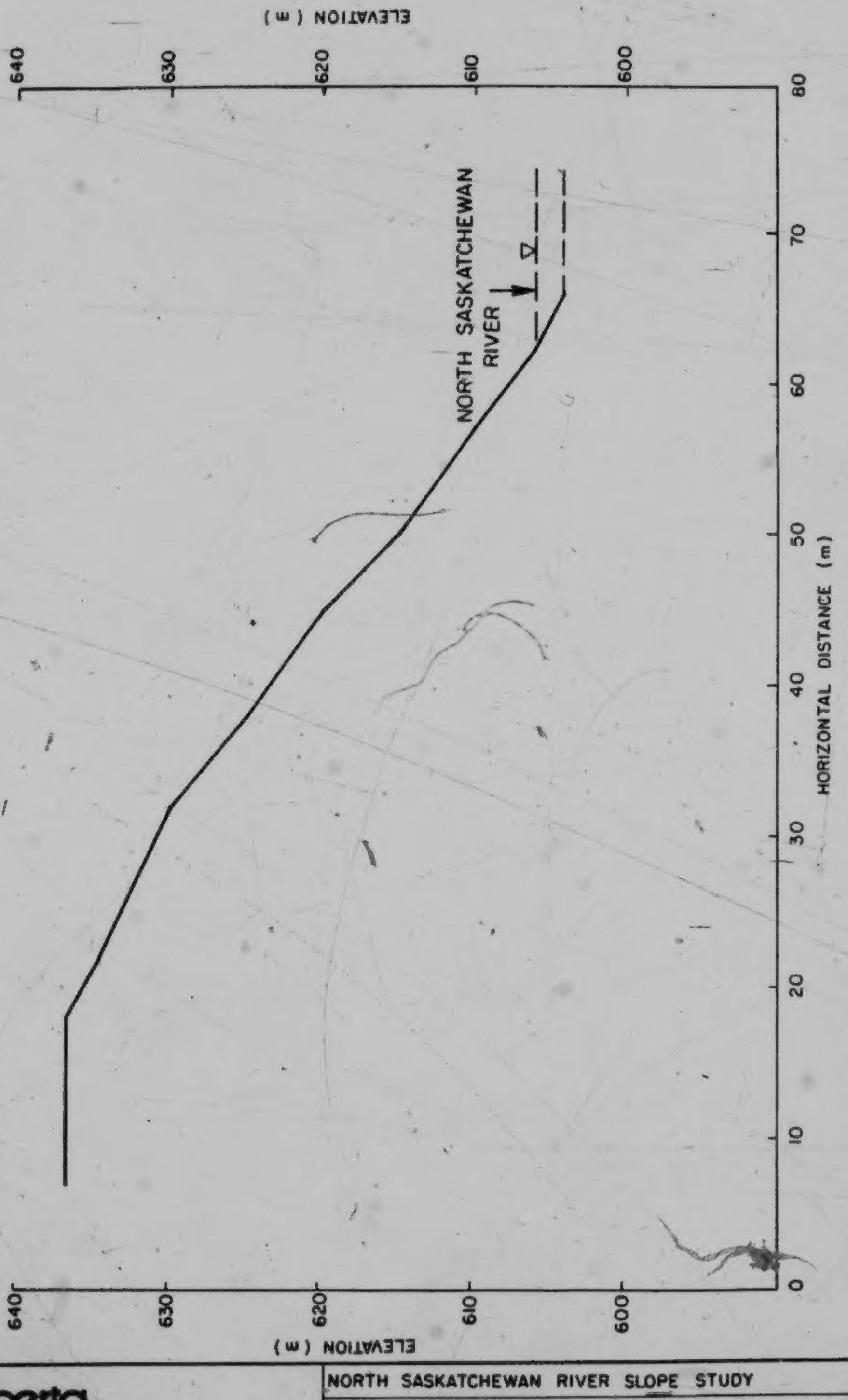
NOTE:
PROFILE CONSTRUCTED FROM 1:5000
CONTOUR MAP (CADASTRAL NUMBER 943-48)



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NORTH SASKATCHEWAN RIVER SLOPE STUDY

PROFILE OF SLOPE MOVEMENT SM-05

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SCALE AS SHOWN
DATE JUNE 1986

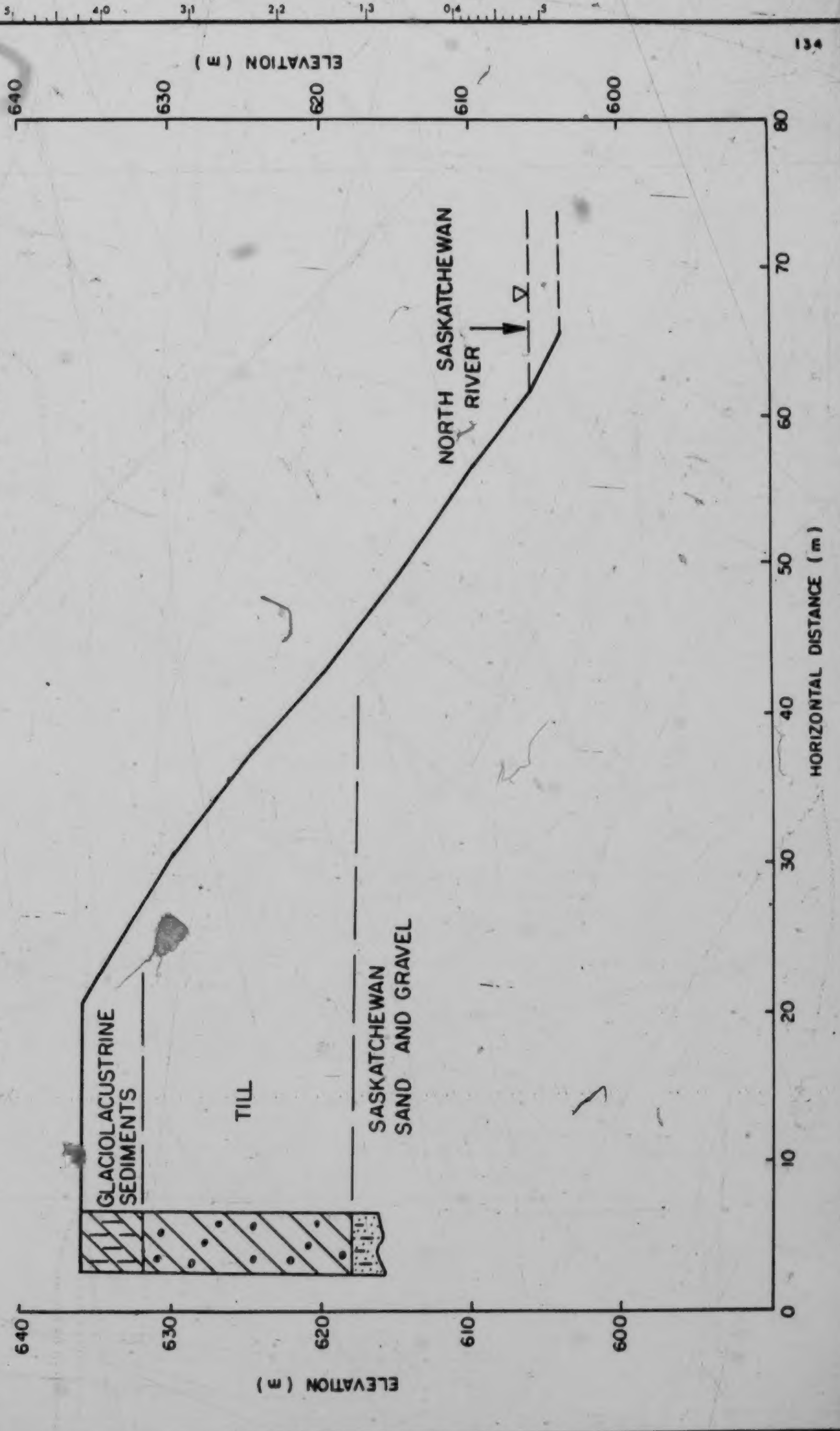
SHEET 1 OF 1
FIGURE 60

Figure 61: Upstream view of slope movement SM-D5

Figure 62: Upstream view of seepage areas along toe of SM-D5

Figure 63: Upslope view of slope movement SM-D6.

NOTES:
1. STRATIGRAPHY MAPPED FROM OUTCROP SECTION IN RIGHT FLANK OF SM - D6
2. PROFILE CONSTRUCTED FROM 1:5000 CONTOUR MAP (CADASTRAL NUMBER 943+48)


ELEVATION (m)
640
630
620
610
600
GLACIOLACUSTRINE SEDIMENTS
TILL
SASKATCHEWAN SAND AND GRAVEL
NORTH SASKATCHEWAN RIVER
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HORIZONTAL DISTANCE (m)

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

PROFILE OF SLOPE MOVEMENT SM - D7

SCALE AS SHOWN	SHEET 1 OF 1
DATE JUNE 1986	FIGURE 64

MICROFILM DATE

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

SLOPE MOVEMENTS SM-D8 TO SM-D10

NW 3-54-23-W4

SCALE 1:2000
DATE JUNE 1986

SHEET 1 OF 1
FIGURE 65

FILE No.

Figure 66: Seepage discharging from sandy glaciolacustrine silts and clays exposed in the main scarp of slope movement SM-D8.

Figure 67: Downslope view of the flow movement below the main scarp of SM-D8.

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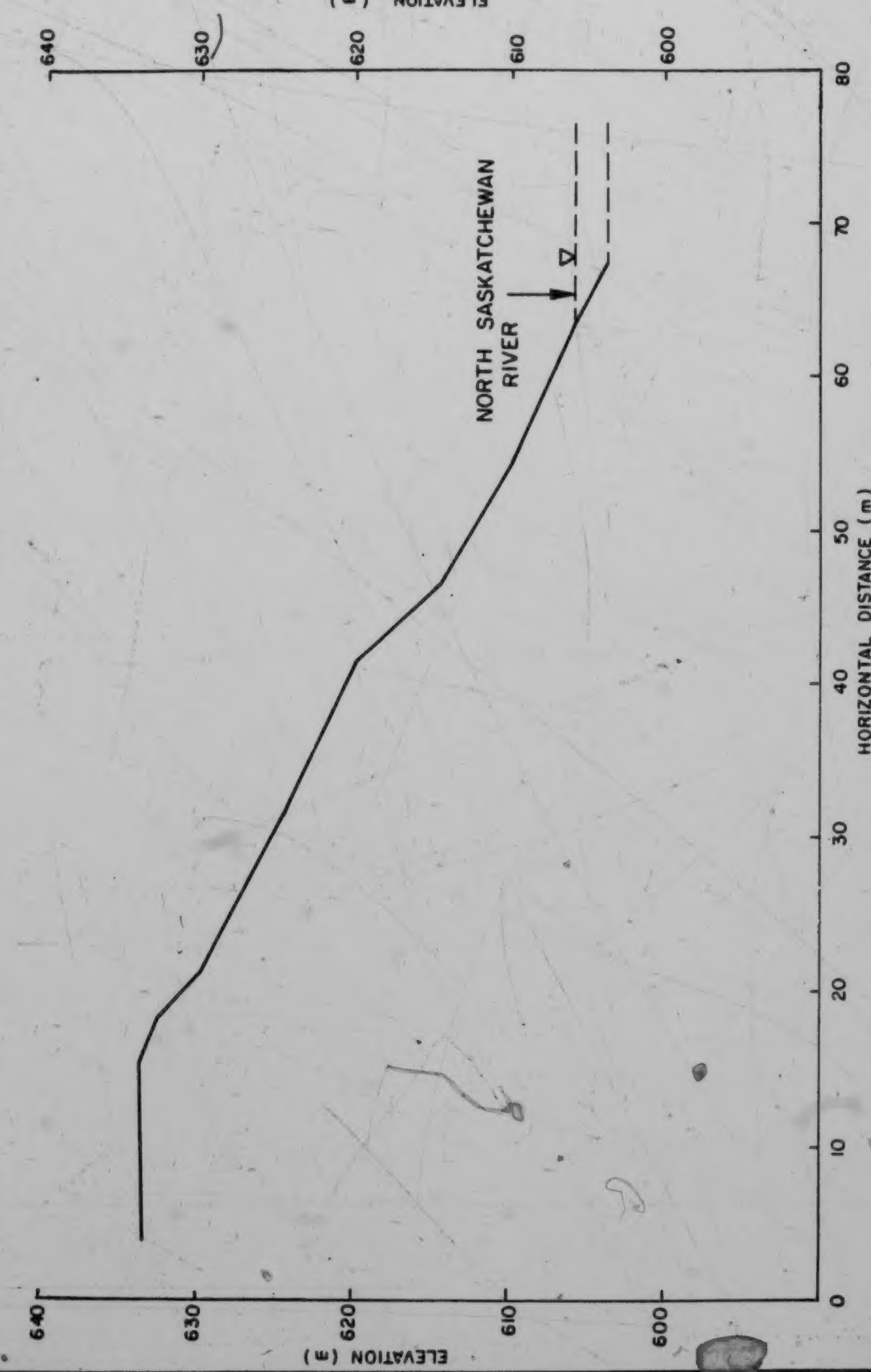
NOTE:
PROFILE CONSTRUCTED FROM 1:5000
CONTOUR MAP (CADASTRAL NUMBER 943+48)



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NORTH SASKATCHEWAN RIVER SLOPE STUDY

PROFILE OF SLOPE MOVEMENT SM - 09

SCALE AS SHOWN	SHEET 1 OF 1
DATE JUNE 1986	FIGURE 68

10 m above the river and is overlain by approximately 15 m of clay till. Above the till, 4 to 5 m of glaciolacustrine silty clays form the upland surface. The position of the groundwater table is probably within 1 to 3 m above river level as indicated by numerous seepage areas along the toe of these slopes which is likely discharging from the Saskatchewan sand and gravel (Figures 12 and 62).

In Area D the same type of movement occurs along the slopes encompassed by SM-D3, SM-D4, SM-D5, SM-D7 and SM-D9 (Table 4; Figures 55, 59 and 65). Profiles constructed from a 1:5000 contour map (Cadastral Number 943+48) show these movements have slope heights which range from 28 to 30 m and average inclinations from 30 to 38 degrees (Table 5; Figures 56, 60, 64 and 68). The steep main scarps of these movements are 3 to 5 m high and are bare of vegetation. Below the scarps there are a series of displaced blocks of glaciolacustrine silty clays and till. These are well-defined in SM-D3 and SM-D5 (Figures 58 and 61). These blocks have an upper surface which is sparsely vegetated with grasses and young trees and they generally decrease in size downslope towards the toe of the movements. The blocks are separated by a sparsely vegetated cover of loose displaced material.

Below the main scarp of SM-D3 there is a relatively intact displaced block (Figure 58). The block is approximately 6 m across its top and 15 to 20 m long. It has moved approximately 5 m out and 4 m down from the valley crest leaving a main scarp that is 4 to 5 m high. From examining older airphotos this block moved to its present position between 1962 and 1972.

It appears that in these movements the displaced blocks are undergoing translational sliding on steeply inclined rupture surfaces formed between the underside of the block and the slope surface. Evidence for the formation of these block movements is exposed in the left flank of SM-D1 where a series of fractures curve down from the crown area and daylight on the slope approximately 4 to 5 m below the valley crest (Figure 57). Airphotos dating back to 1924 show that these movements are slow as there has been only minor changes to the slope configurations over the past 60 years.

Other important slope movements in Area D include SM-D6 and SM-D8 which are both flows (Figures 59 and 65). Slope movement SM-D6 is associated with a V-shaped gully eroded by run-off from the uplands into a slope which is 29 m high (Table 5; Figure 63). The steep sides of the gully are unvegetated and formed by up to 15 m of columnar jointed till overlain by 4.5 m of displaced glaciolacustrine silty clays (Figure 11). Less than 0.5 m of silty sand which is laminated to cross-bedded is exposed at the base of the till, extending below the cover of displaced material. In the centre of the gully a flow movement is formed by saturated overburden soils which bulges out into the river at the toe.

As observed on older airphotos erosion of the gully began after 1950 and was well-developed by 1962 . Since its formation the head of SM-D6 has regressed 3 to 7 m back into the uplands.

Slope movement SM-D8 has occurred in a 29 m high slope located below a homestead (Table 5; Figure 65). The main scarp of this movement is 4 to 7.5 m high. The scarp face is steep and unvegetated exposing glaciolacustrine sandy silts and clays from which the seepage is discharging (Figure 66). Below the main scarp saturated displaced material and clumps of vegetation are flowing down the slope to bulge into the river at the toe (Figure 67). This flow movement did not exist on the 1962 airphotos but was well-developed by 1972 coinciding with the construction of a homestead on the uplands. Since initiation it has caused less than 1 m of valley crest regression.

4.3.5 Slope Movement Area E

Slope Movement Area E is located along the outside of a broad meander stretching from SW27-53-23-W4 to SE34-53-23-W4 (Figures 1 and 104; Appendix 1). Through this meander the river is at an elevation of approximately 608 m and changes flow direction from easterly to northwesterly with its main current along the toe of the 32 to 33 m high valley slopes.

Along the outside of this meander thirteen slope movements designated SM-E1 to SM-E13 occur as mapped on Figures 69, 72 and 75 and summarized in Table 4. Profiles of slope movements SM-E1, SM-E3 and SM-E13 are shown on Figures 70, 71 and 78 respectively. Photographs showing the features of slope movements SM-E6, SM-E8 and SM-E13 are presented as Figures 73, 74, 76 and 77.

Previous investigations by Thomson (1971) of the "Lesueur Landslide" at the upstream end of Area E in SW27-53-23-W4 encountered the overburden-bedrock contact at approximately 15 m above river level (Figure 70). The bedrock strata which belongs to the Horseshoe Canyon Formation consisted of interbedded clay shale, bentonitic clay shale and sandstone. The shales were interbedded with a bentonite seam 150 mm in thickness and coal beds less than 0.6 m in thickness. The bedrock was found to be overlain by approximately 17 m of overburden soils which consisted of 6 m of Saskatchewan sand and gravel overlain by 5.5 m of clay till which in turn was overlain by 6.5 of glaciolacustrine silty sands extending to the upland surface. Piezometric water levels reported by Thomson (1971) showed that the groundwater table rose from being just above river level at the toe of the movement to above the overburden-bedrock contact in Saskatchewan sand and gravel behind the slope.

Outcrop sections mapped by the writer on unmoved slopes approximately 1.5 km further downstream in SE34-53-23-W4 reveal a similar stratigraphy as delineated by Thomson (1971) but with the overburden-bedrock contact slightly lower in the slopes at approximately

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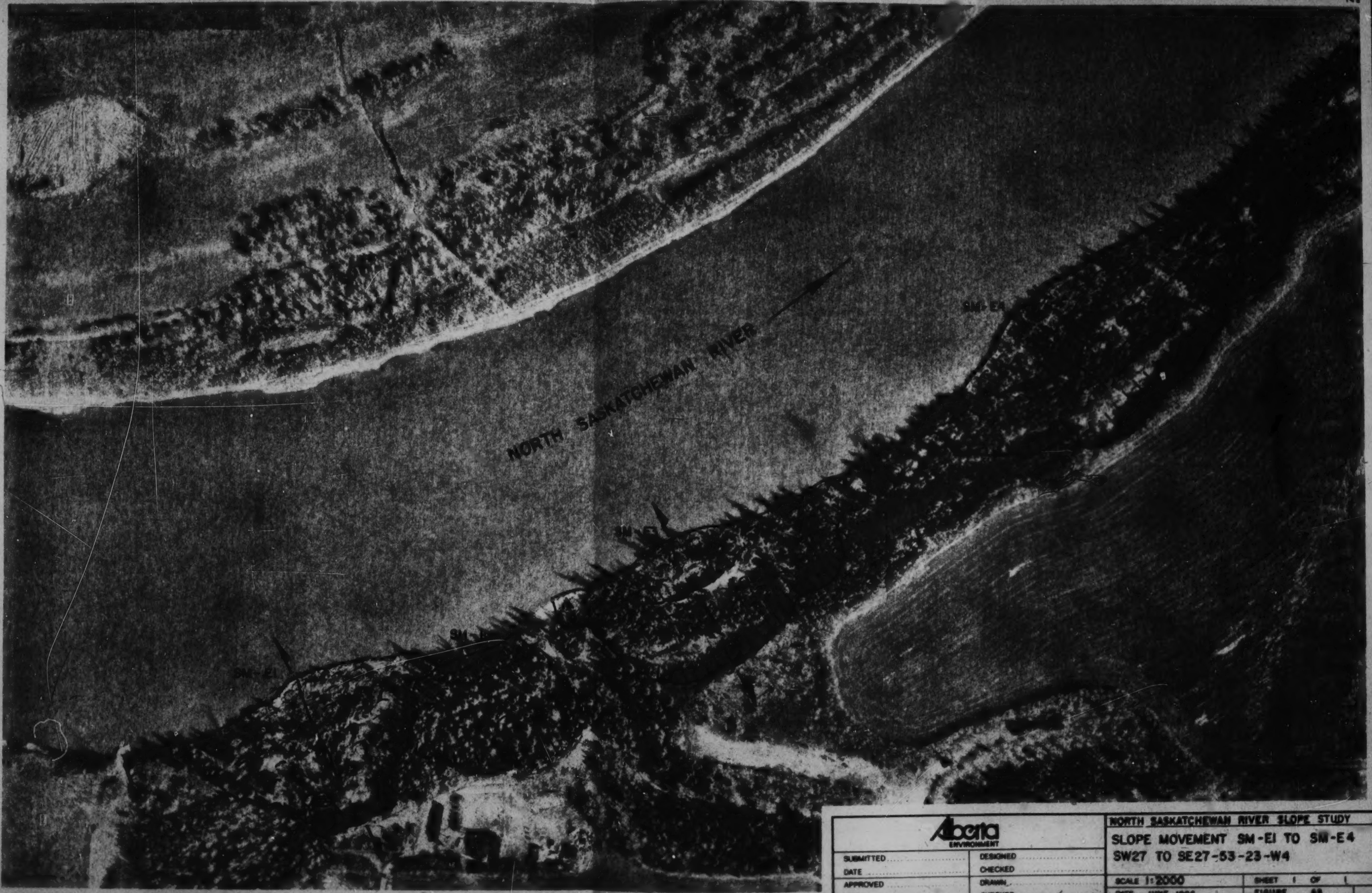
SM-E4
NORTH SASKATCHEWAN RIVER
SM-E1

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

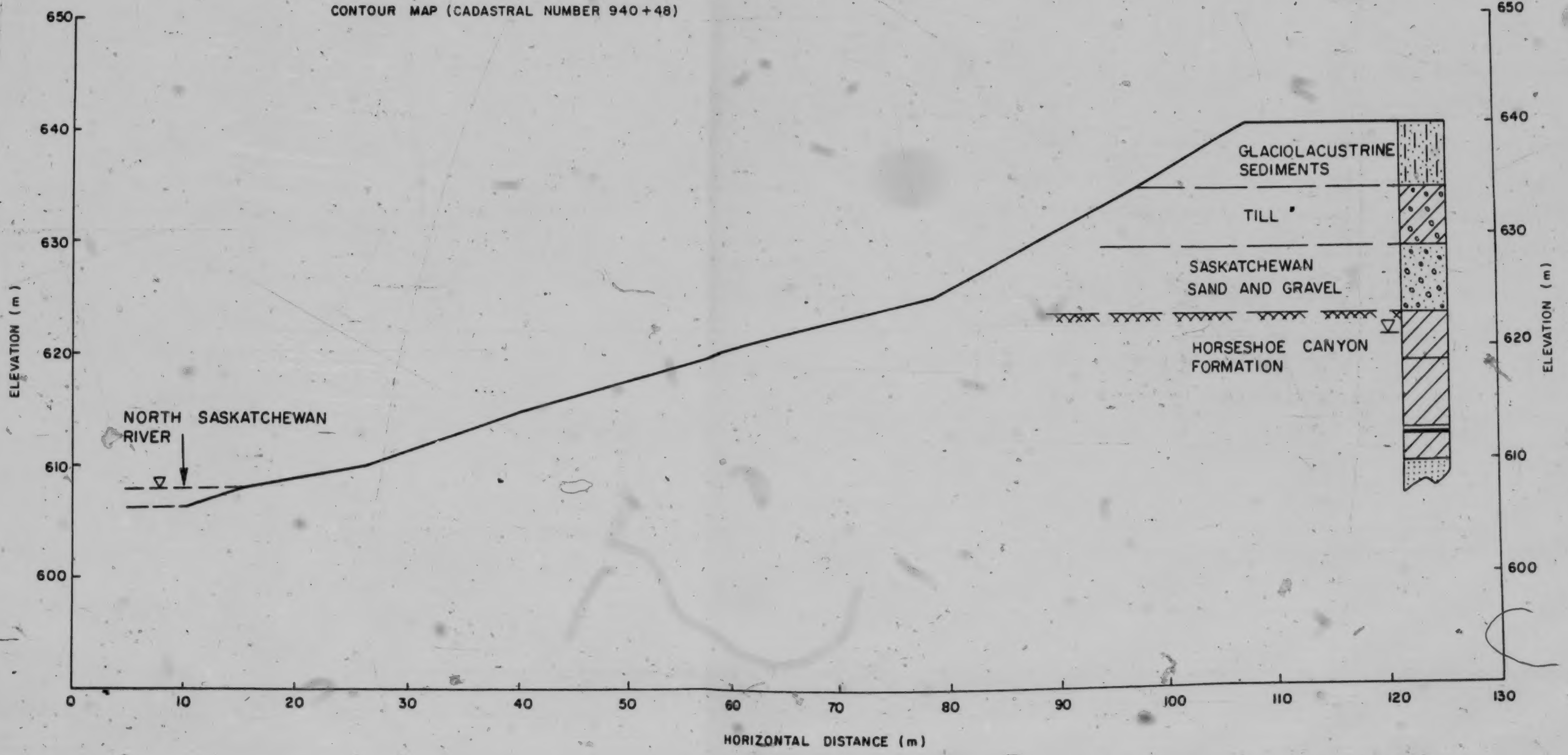
SLOPE MOVEMENT SM-EI TO SM-E4
SW27 TO SE27-53-23-W4

SCALE 1:2000
SHEET 1 OF 1
DATE JUNE 1986
FIGURE 69

MICROFILM DATE

NOTES:

1. STRATIGRAPHY INFERRED FROM SUBSURFACE INVESTIGATIONS BY THOMSON (1971)
2. PROFILE CONSTRUCTED FROM 1:5000 CONTOUR MAP (CADASTRAL NUMBER 940+48)


650
640
630
620
610
600
ELEVATION (m)
NORTH SASKATCHEWAN RIVER
GLACIOLACUSTRINE SEDIMENTS
TILL
SASKATCHEWAN SAND AND GRAVEL
HORSESHOE CANYON FORMATION
0
10
20
30
40
50
60
70
80
90
100
110
120
130
HORIZONTAL DISTANCE (m)

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DESIGN AND CONSTRUCTION DIVISION

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

PROFILE OF SLOPE MOVEMENT SM-E1

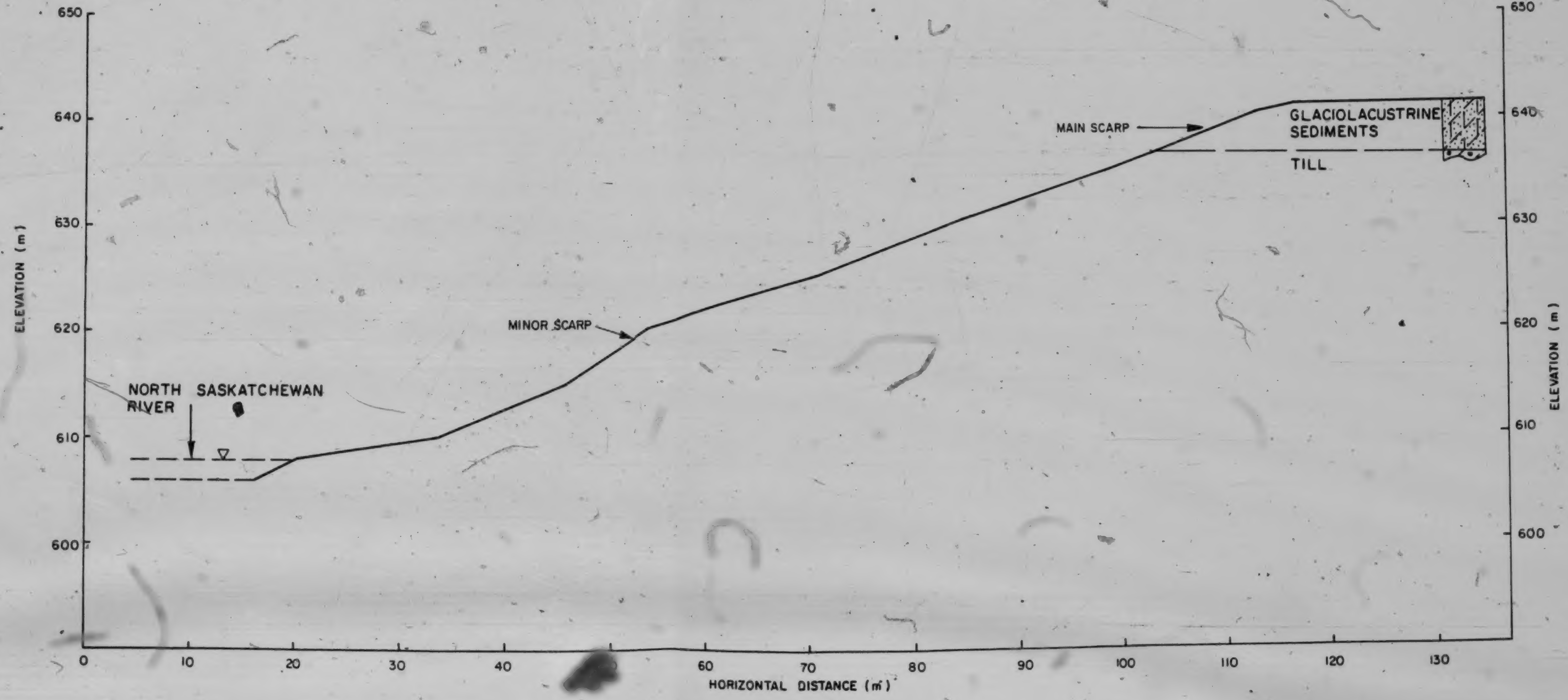
SCALE AS SHOWN
DATE JUNE 1986
SHEET 1 OF 1
FIGURE 70

P3-280x430

MICROFILM DATE

NOTES:

1. STRATIGRAPHY MAPPED FROM OUTCROP SECTION IN MAIN SCARP.
2. PROFILE CONSTRUCTED, FROM 1:5000 CONTOUR MAP (CADASTRAL NUMBER 940+48)



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Alberta ENVIRONMENT	DESIGN AND CONSTRUCTION DIVISION	NORTH SASKATCHEWAN RIVER SLOPE STUDY
SUBMITTED	DESIGNED	PROFILE OF SLOPE MOVEMENT SM-E3
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APPROVED	DRAWN	SCALE AS SHOWN / SHEET 1 OF 1
DATE	CHECKED	DATE JUNE 1986 / FIGURE 71

P3-280x430

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50

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

SLOPE MOVEMENTS SM-E6 AND SM-E7

NW 27 TO NE 27-53-23-W4

SCALE 1:2000

SHEET 1 OF 1

Figure 73: Upslope view of slope movement SM-E6.

Figure 74: Downstream view of the seepage area adjacent to the left flank of SM-E6.

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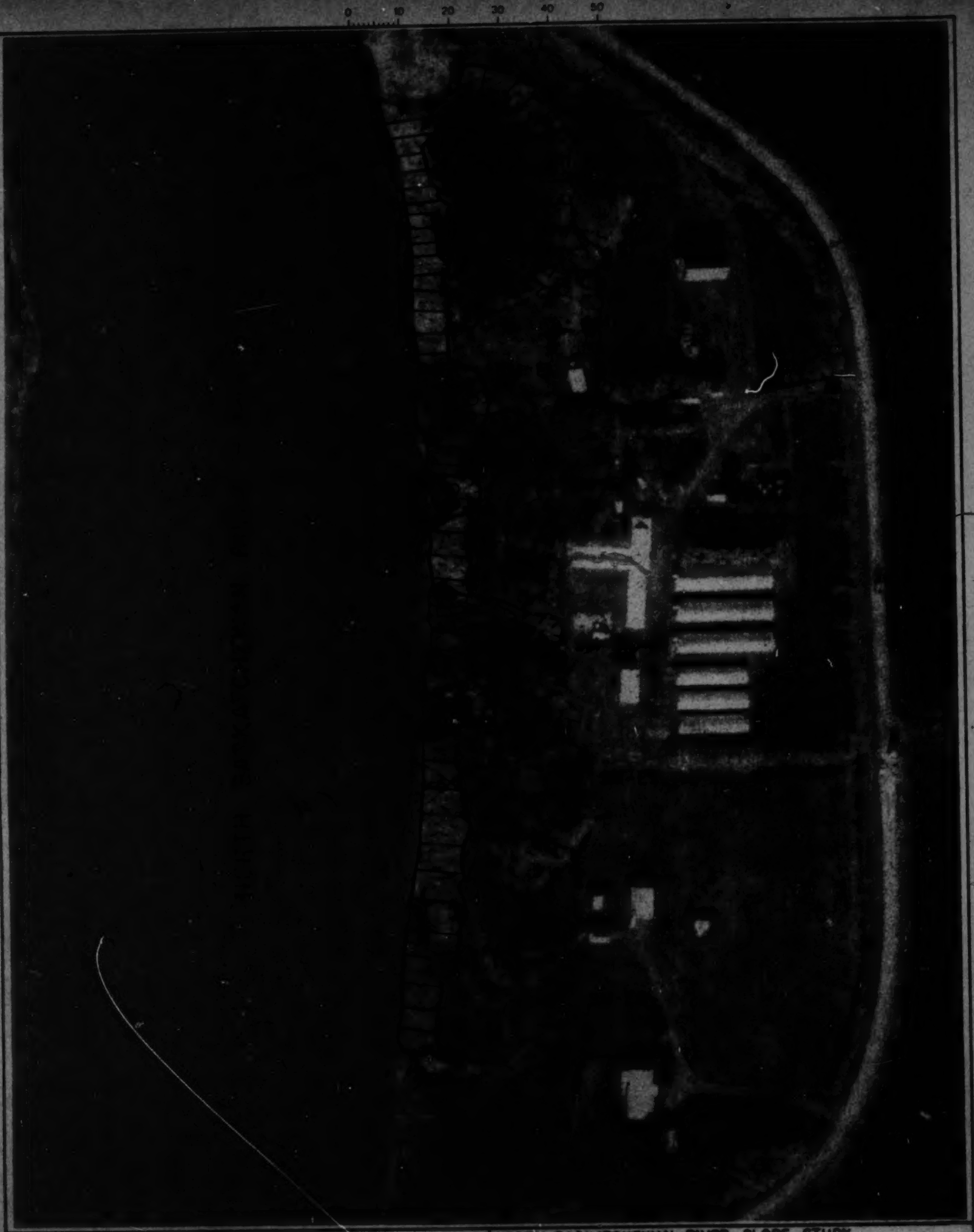

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

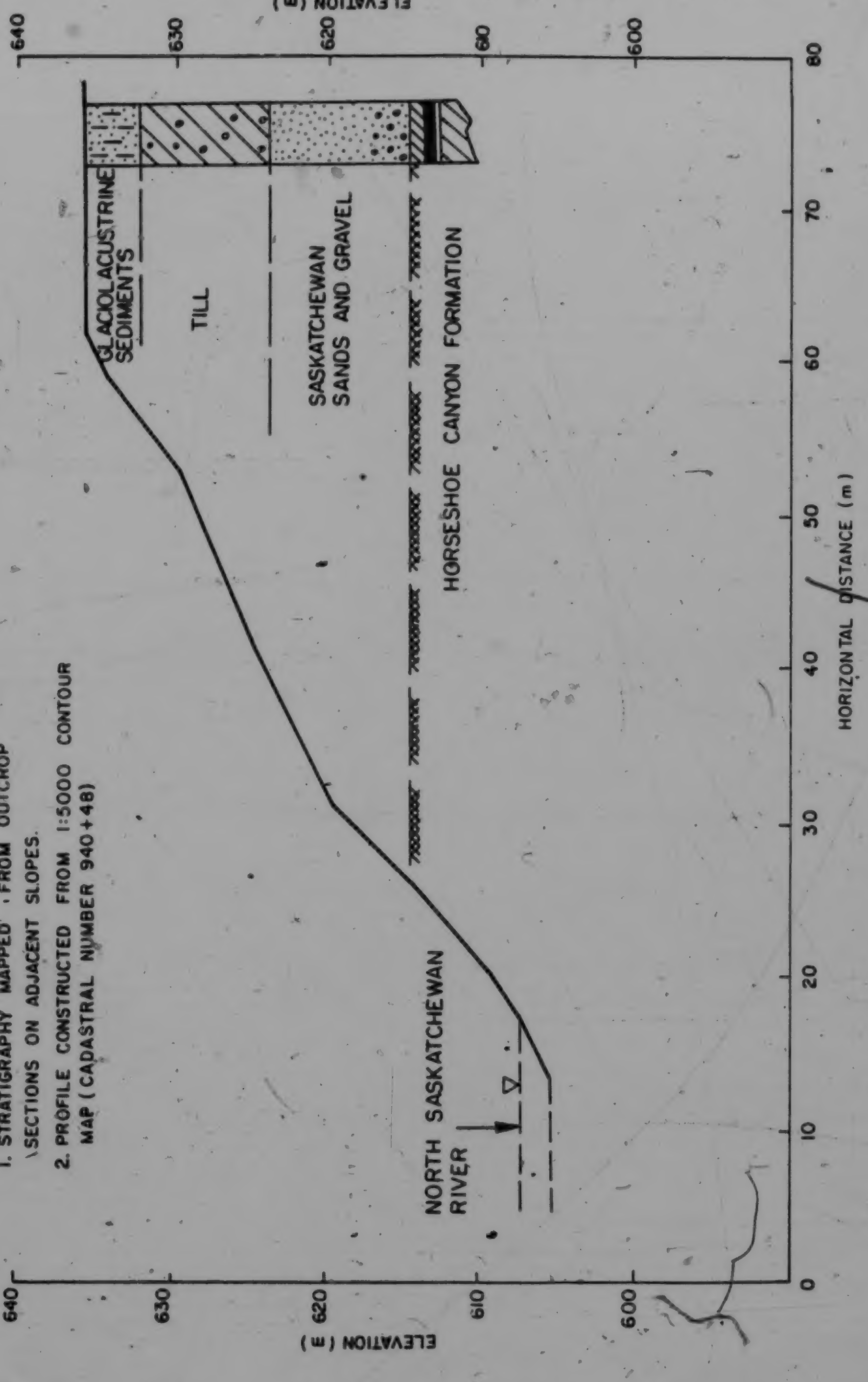
SLOPE MOVEMENTS SM - E8 TO SM - E13

NE 27 TO SE 3 - 53 - 23 - W4

SCALE 1:2000

SHEET 1 OF 1

Figure 76: Displaced blocks of till overlying insitu silty shale strata exposed in a 9 to 10 m high slope below the toe of slope movement SM-E8. Note the absence of Saskatchewan sand and gravel.


ELEVATION (m)
640
630
620
610
600
GLACIOLACUSTRINE SEDIMENTS
TILL
SASKATCHEWAN SANDS AND GRAVEL
HORSESHOE CANYON FORMATION
NORTH SASKATCHEWAN RIVER
HORIZONTAL DISTANCE (m)
0
10
20
30
40
50
60
70
80

NOTES:

1. STRATIGRAPHY MAPPED FROM OUTCROP SECTIONS ON ADJACENT SLOPES.
2. PROFILE CONSTRUCTED FROM 1:5000 CONTOUR MAP (CADASTRAL NUMBER 940+48)

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

PROFILE OF SLOPE MOVEMENT SM - E13

SCALE AS SHOWN	SHEET 1 OF 1
DATE JUNE 1986	FIGURE 77

Figure 78: Displaced block of till which has moved down over Saskatchewan sand and gravel as exposed at the toe of slope movement SM-E13.

7 m above river level (Figures 8 and 78). Seepage areas on these slopes indicates that the groundwater table in this segment of Area E is near the overburden-bedrock contact.

Although the slope stratigraphy remains relatively the same throughout Area E, three groups of movements occur based on probable type of movement and position of the rupture surface. The first group includes slope movements SM-E1, SM-E3 and SM-E4 which occur in S1/2 27-53-23-W4 upstream of the midpoint in the meander (Table 4; Figure 69). Slope movement SM-E1 is the "Lesueur Landslide" which was investigated by Thomson (1971). A profile constructed from a 1:5000 contour map (Cadastral Number 940+48) by the writer shows this movement occurred in a 32 m high slope and left an average inclination to 17 degrees (Table 5; Figure 70).

Thomson (1971 pp. 5-6) observed the occurrence of the movement on September 3, 1963:

> "By mid July, a distinct scarp had developed which by mid August had increased to 12 to 14 inches (30.5 to 35.6 cm) high. The situation continued to deteriorate slowly and on September 3, 1963 at 10 a.m., the scarp had increased to 2 feet (0.6 m). By 8 p.m. the same day it was some 6 feet high. At 8 a.m. the following day, September 4, the scarp was 22 feet (6.7 m) high and a corner of the house was cantilevered over the edge. There were no signs of distress in the basement wall or floor other than a minor spalling off of a thin dressing mortar that had, presumably, been originally applied below the ground line as a waterproofing. From the original valley wall to the scarp the maximum distance

> was some 50 feet (15.2 m). The slide was 170 feet (51.8 m) wide at the top but fanned out to nearly 1000 feet (304.8 m) at river level. At the time of failure, the lawn was 105 feet (32 m) above river level. At the toe, the river bank averaged 10 feet (3.1 m) above river level. During the day of failure, material at the toe was observed to move out along a practically horizontal plane and, after a small amount of cantilevering, chunks dropped off into the river where they accumulated. There was no apparent upward movement at the toe. As toe debris accumulated, cracks opened up parallel to the river bank and a few feet back from it. The next day, the toe area was a jumble of blocks and soft ground with some fallen trees to add to the disorder. The planar movement observed during failure was not in evidence."

From his investigation and analysis Thomson, (1971) attributed the main cause of SM-E1 as being progressive removal of a small terrace at the toe by river erosion. Erosion of the terrace caused repeated unloading and saturation of the terrace soils which decreased their resistance to movement and the stabilizing effect of providing a toe load.

Mapping by the writer in the field suggests that slope movements SM-E3 and SM-E4 have configurations and geomorphological features similar to SM-E1 (Table 4; Figure 69). Profiles constructed from a 1:5000 contour map (Cadastral Number 940+48) shows that SM-E3 is 33 m high and has an average inclination of 20 degrees while SM-E4 is 32 m high with an average inclination of 22 degrees (Table 5; Figures 71). They have sharp unvegetated main scarps approximately 10 m high formed by glaciolacustrine silty to clayey sands. The main bodies below the scarp are densely vegetated with mature trees several of which are leaning in various directions. The surface of both movements are disrupted by traverse ridges separated by vegetated depressions and deep cracks some of which contain ponded water. About halfway down the movements, unvegetated downslope faces of a major transverse ridge forms a minor scarp above mounds of displaced reworked bedrock material in the toe area. Seepage is occurring at the base of this scarp in SM-E4 and in the toe area of SM-E3. These seepage areas likely represent perched water tables within the displaced material.

The similarity in features to SM-E1 indicates that SM-E3 and SM-E4 also probably underwent translational movement and displaced bedrock material in the toe of both movements indicate a rupture surface in bedrock strata at or just below river level. Both SM-E3 and SM-E4 are absent on the 1924 airphotos but exist on the 1950 airphotos indicating they are between 35 and 60 years old. On the 1950 airphotos the bulge of displaced material at the toe of each movement is more irregular and larger than present indicating that river erosion has been occurring.

The second group of slope movements in Area E includes SM-E6, SM-E10 and SM-E12 situated in NE27 and SE 34-53-23-W4 (Figures 72 and 75). They are flow movements associated with seepage areas and erosion gullies. All of these movements occur on 29 to 30 m high slopes, below homesteads located on the adjacent uplands.

Slope movements SM-E6 and SM-E10 are associated with V-shaped gullies eroded by run-off from the uplands. In both movements, saturated displaced material eroded from the gully has flowed out in the toe area to form a bulge into the river. The gully at SM-E6 has steep unvegetated sides approximately 4 to 6 m high (Figure 73). It is cut down through overburden soils in the upper three quarters of the slope and bedrock below. On the upstream side of the gully, seepage is discharging at a level which approximately corresponds to the overburden-bedrock contact exposed in the gully (Figure 74). Below the seepage there is a steep bedrock slope which is experiencing small flow movements due to saturation of the surficial layer.

On the 1972 airphotos SM-E6 appears as a narrow gully eroded into the uplands. Its formation coincided with the construction of the homestead at the top of the slope between 1950 and 1972. Since 1972 the continued erosion of the gully has resulted in approximately 3 m of valley crest regression.

Slope Movement SM-E10 is a shallow gully with gently sloping sides less than 4 m high. It is vegetated with grasses on the upper part of the slope while a bulge of displaced material at the toe is sparsely vegetated with grasses. There are no fresh erosion features in the gully. This movement is not present on the 1924 airphotos but exists on the 1950 airphotos in which time a homestead was constructed on the adjacent uplands. It has since remained dormant and has become vegetated while the homestead has since expanded with additional outbuildings and greenhouses.

Slope movement SM-E12 involves the lower 2 to 5 m of overburden soils and the underlying bedrock. Seepage is discharging from a zone at approximately 6 to 8 m above the river level near the contact between the Saskatchewan sand and gravel and underlying bedrock. Saturation of the surficial bedrock material exposed below the seepage is causing a flow movement which forms a slight bulge into the river at the toe. Displacement of the bedrock material and washing out of the Saskatchewan sand and gravel appears to be causing slumping of overlying blocks of till. Slope movement SM-E12 is evident on the 1950 airphotos. The homestead with outbuildings and greenhouses located behind SM-E10 also extends north to above SM-E12.

The third group of slope movements in Area E includes SM-E7, SM-E8, SM-E9, SM-E11 and SM-E13 which occur in NE27 and SE34-53-23-W4 (Figures 72 and 75). Profiles constructed from a 1:5000 contour map (Cadastral Number 940+48) indicates these movements have average inclinations of 22 to 30 degrees and are 28 to 30 m high (Table 5; Figure 78). Below the toe of these movements a steep slope of insitu bedrock strata extends approximately 9 to 10 m above river level. Along the toe of SM-E7 a distorted mass of overburden soils and upper layers of bedrock is exposed at the top of this slope while at the toe of SM-E8 and SM-E13 displaced blocks of till directly overlies bedrock (Figures 6, 7, 76 and 77). Above this lower slope of bedrock the rounded, hummocky surface of these movements are densely vegetated with mature trees. The main scarps are also densely treed and have gently sloping faces. The scarp outlines are fairly arcuate with rounded crown and lateral margins.

The type of these movements is undetermined, but their displaced material primarily consists of overburden soils as exposed above rupture surfaces that are within 0.25 m below the overburden- bedrock contact. All of these movements exist on the 1924 airphotos and have remained dormant over the past 60 years. Their degraded geomorphic features and dense, mature vegetation suggests an inactive-mature age class.

4.3.6 Slope Movement Area F

Slope Movement Area F is located along the outside of a broad meander stretching from SE30 to NW28-53-23-W4 at the upstream end of the study area (Figures 1 and 103; Appendix 1). The river enters this meander flowing in a northerly direction and exits flowing east. Along the outside of this meander the valley slopes rise 33 to 39 m above river level which is at an elevation of approximately 608 m. In Area F three slope movements designated SM-F1 to SM-F3 occur in these slopes as mapped on Figures 79, 81 and 83 and summarized in Table 4.

Profiles of slope movements SM-F1, SM-F2 and SM-F3 are shown on Figures 80, 82 and 84 respectively.

The stratigraphy of the slopes is inferred from subsurface investigations performed by R.M. Hardy Associates Ltd. (1976) for the Clareview Subdivision on the adjacent uplands. These investigations indicated that the slopes are comprised of overburden soils with the bedrock contact at approximately 2 m below river level (Figure 80). Above river level the overburden sequence consists of 17 m of Saskatchewan sand and gravel overlain by 16.5 m of clay till. The till is overlain by 4.5 m of glaciolacustrine clays which extend to the upland surface. Water levels taken by R.M. Hardy Associates Ltd. (1976) indicated that the groundwater table is in the Saskatchewan sand and gravel at depths of between 25.5 to 32 m (Figure 80).

Slope movements SM-F1 and SM-F2 occur in the upstream portion of Area F while SM-F3 is at the downstream end (Figures 79, 81 and 83). All three movements have similar configurations and features. A profile constructed from a 1:5000 contour map (Cadastral Number 940+44) shows that SM-F1 is approximately 39 m high and has an average inclination of 25 degrees (Table 5; Figure 80). Its main scarp is approximately 15 m high and is vegetated with grasses and young trees. The margins of the scarp are fairly sharp and at its base there is a shallow depression formed by a backslope surface of the main body. The surface of the main body is densely treed and is

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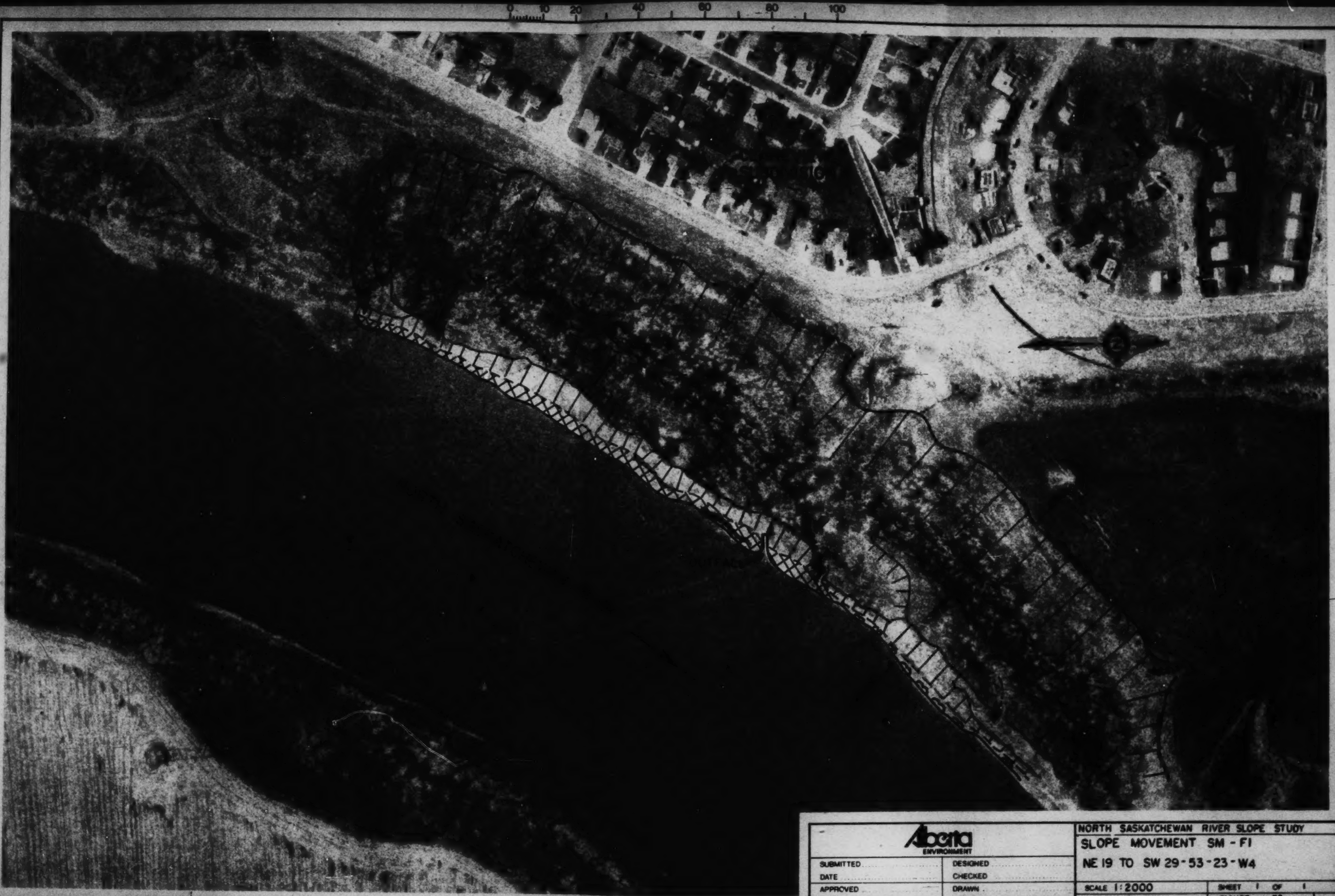

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CENTRAL FILE No.

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APPROVED	DRAWN
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NORTH SASKATCHEWAN RIVER SLOPE STUDY

SLOPE MOVEMENT SM - F1

NE 19 TO SW 29-53-23-W4

SCALE 1:2000	SHEET 1 OF 1
DATE JUNE 1986	FIGURE 79

FS-280x430

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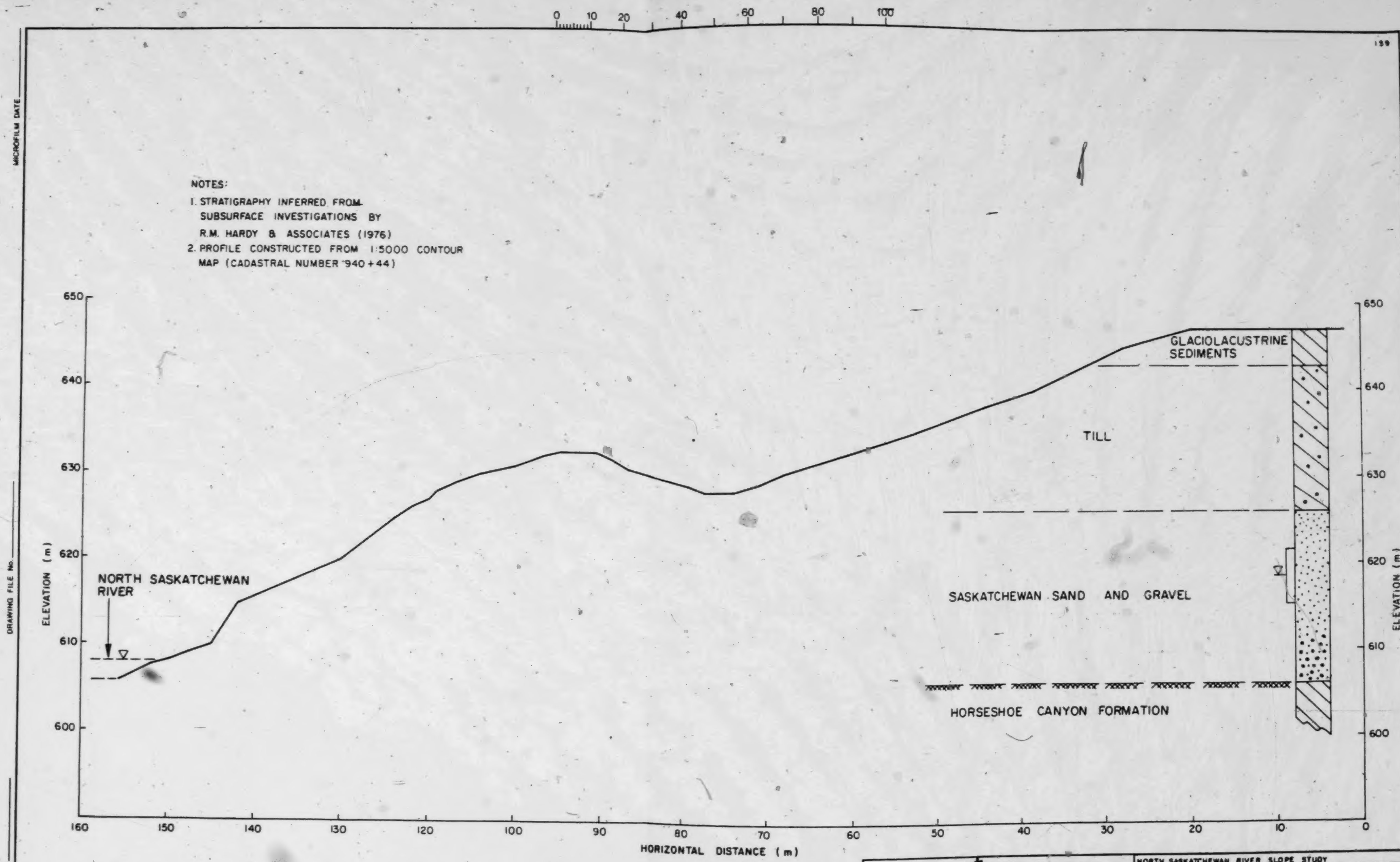
NOTES:

1. STRATIGRAPHY INFERRED FROM SUBSURFACE INVESTIGATIONS BY R.M. HARDY & ASSOCIATES (1976)
2. PROFILE CONSTRUCTED FROM 1:5000 CONTOUR MAP (CADASTRAL NUMBER 940+44)



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Alberta ENVIRONMENT DESIGN AND CONSTRUCTION DIVISION

NORTH SASKATCHEWAN RIVER SLOPE STUDY

PROFILE OF SLOPE MOVEMENT SM-F1

SUBMITTED	DESIGNED	SCALE AS SHOWN
DATE	CHECKED	SHEET 1 OF 1
APPROVED	DRAWN	DATE JUNE 1986
DATE	CHECKED	FIGURE 60

P3-280×430

MICROFILM DATE

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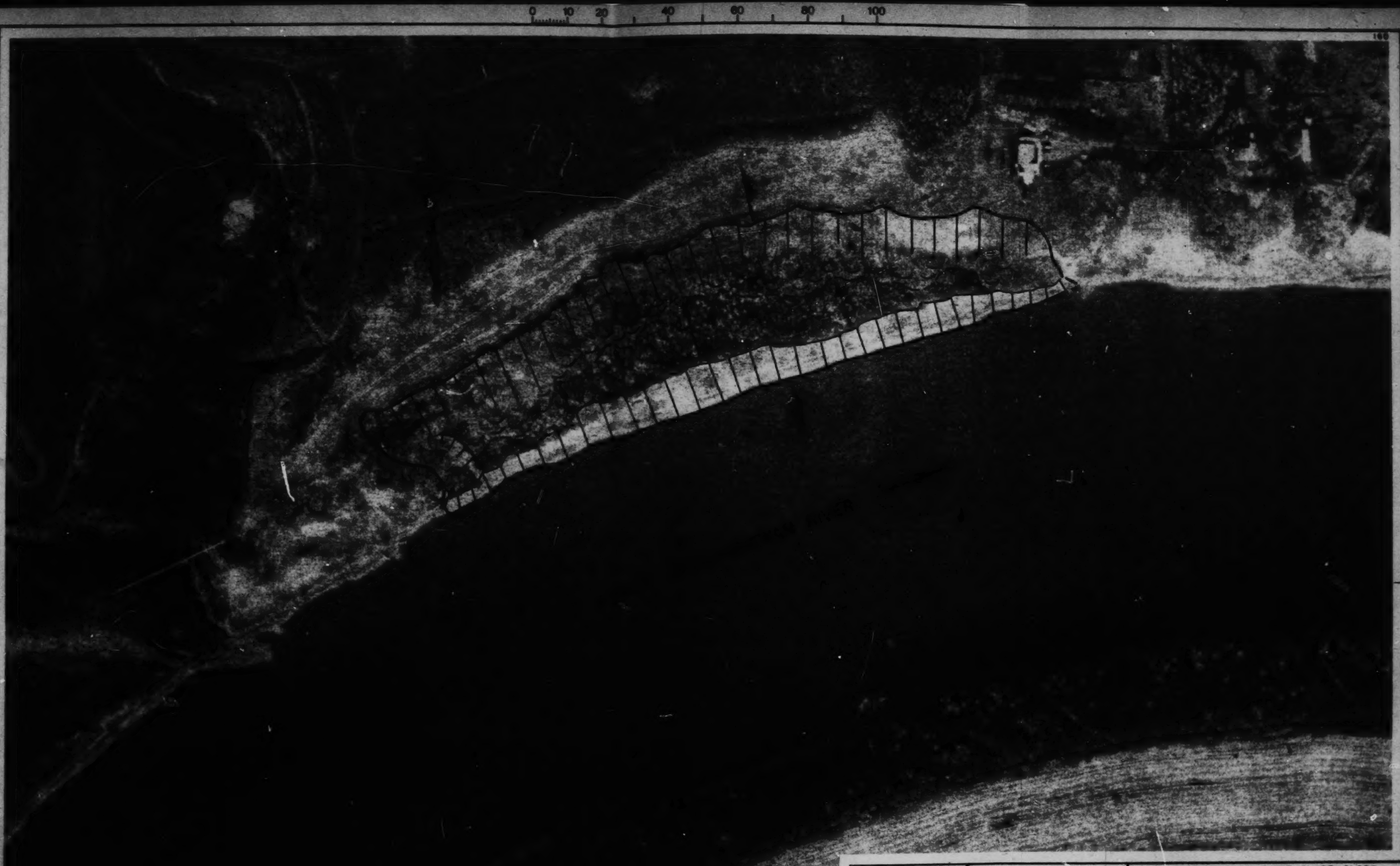

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DATE	CHECKED

NORTH SASKATCHEWAN RIVER SLOPE SLOPE

SLOPE MOVEMENT SM - F2
NW 29 - 53 - 23 - W4

SCALE 1:2000	SHEET 1 OF 1
DATE JUNE 1986	FIGURE 81

MICROFILM DATE

DRAWING FILE No.

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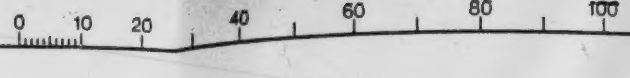
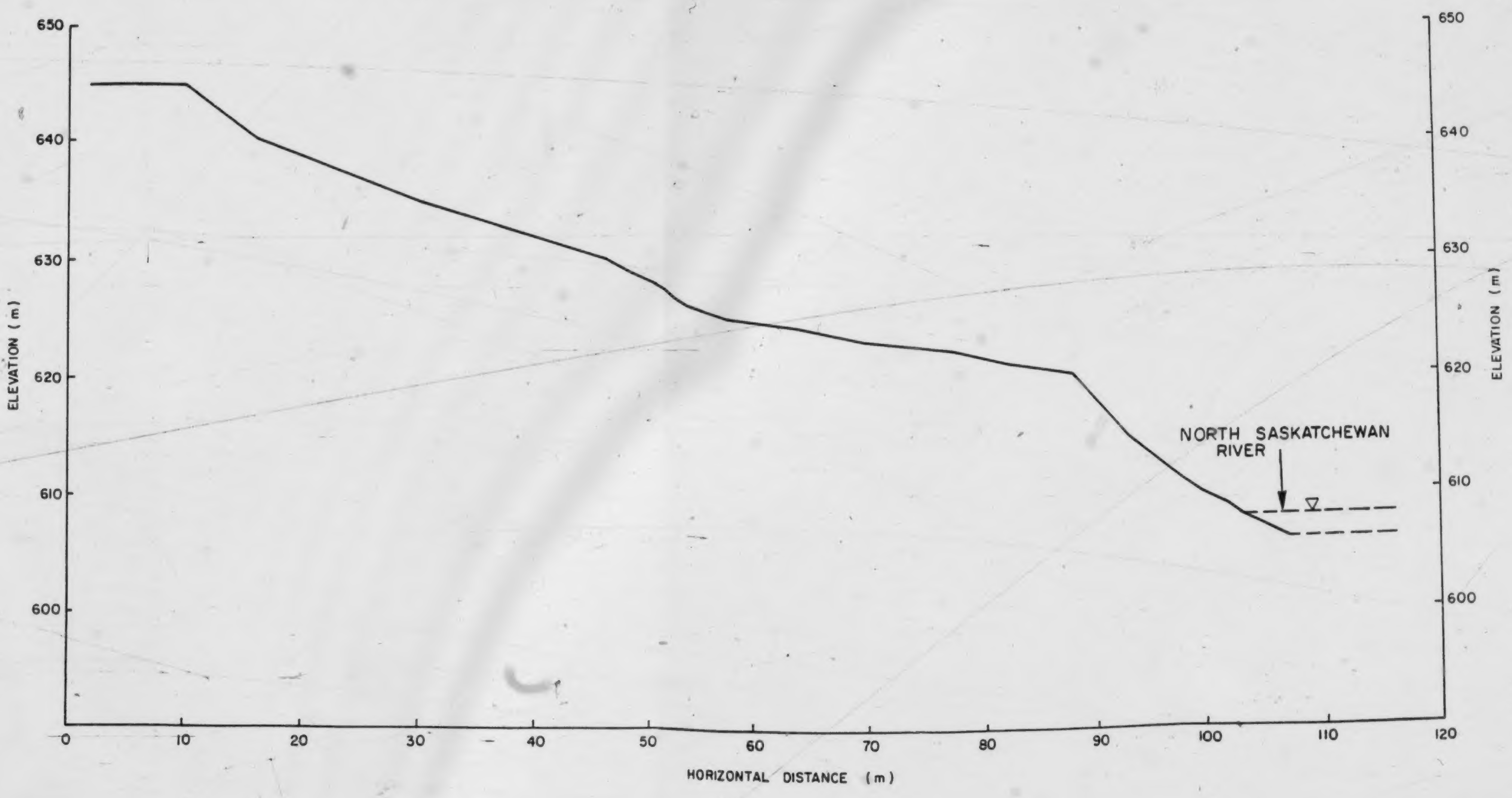


NOTE:
PROFILE CONSTRUCTED FROM 1:5000
CONTOUR MAP (CADASTRAL NUMBER 940+44)



Alberta ENVIRONMENT DESIGN AND CONSTRUCTION DIVISION		NORTH SASKATCHEWAN RIVER SLOPE STUDY
SUBMITTED	DESIGNED	PROFILE OF SLOPE MOVEMENT SM-F2
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APPROVED	DRAWN	SCALE AS SHOWN / SHEET 1 OF 1
DATE	CHECKED /	DATE JUNE 1986 / FIGURE 62

P3-280x430

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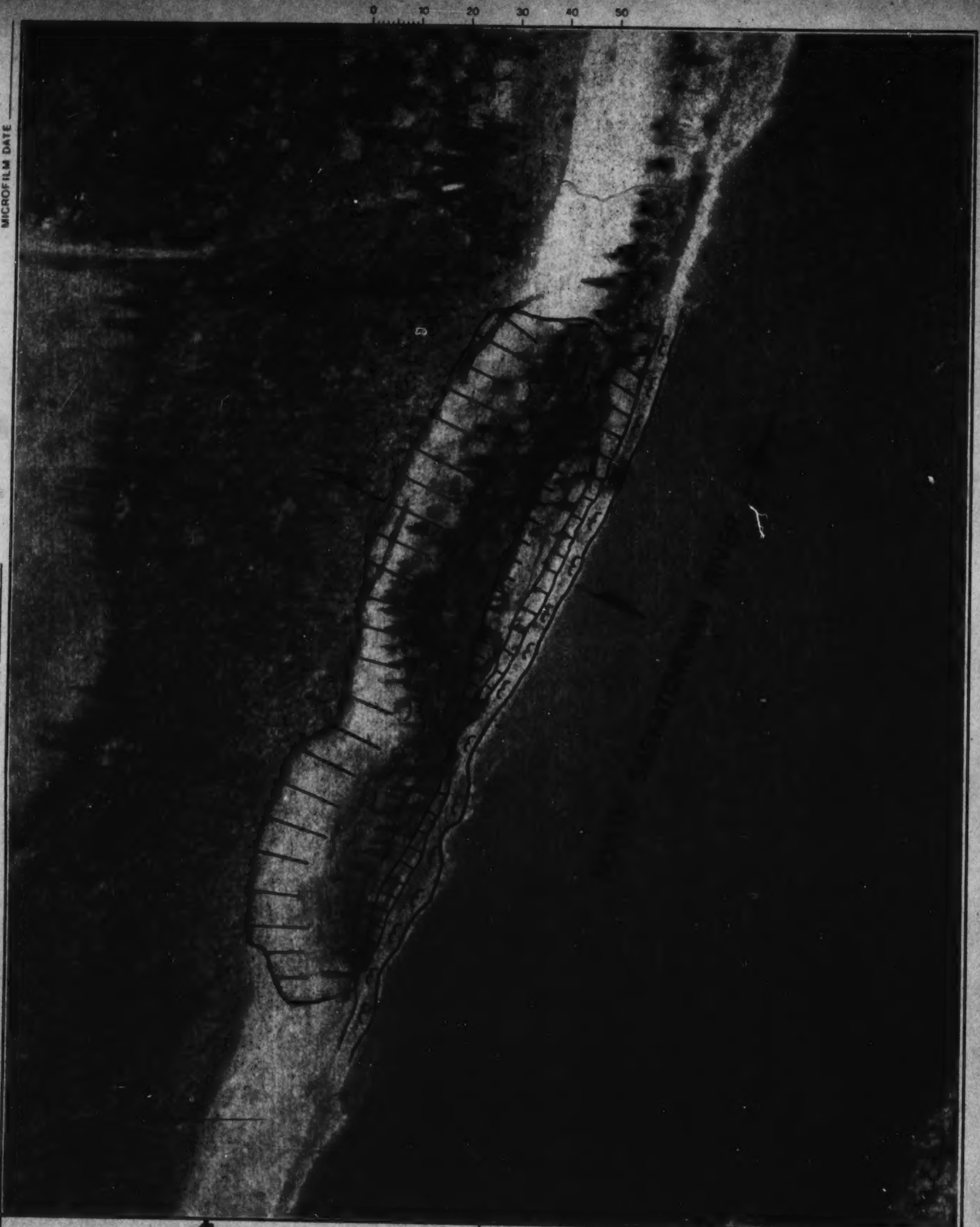

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ENVIRONMENT

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SLOPE MOVEMENT SM - F3

NW 28 - 53 - 23 - W4

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SCALE 1:2000
DATE JUNE 1986
SHEET 1 OF 1
FIGURE 83

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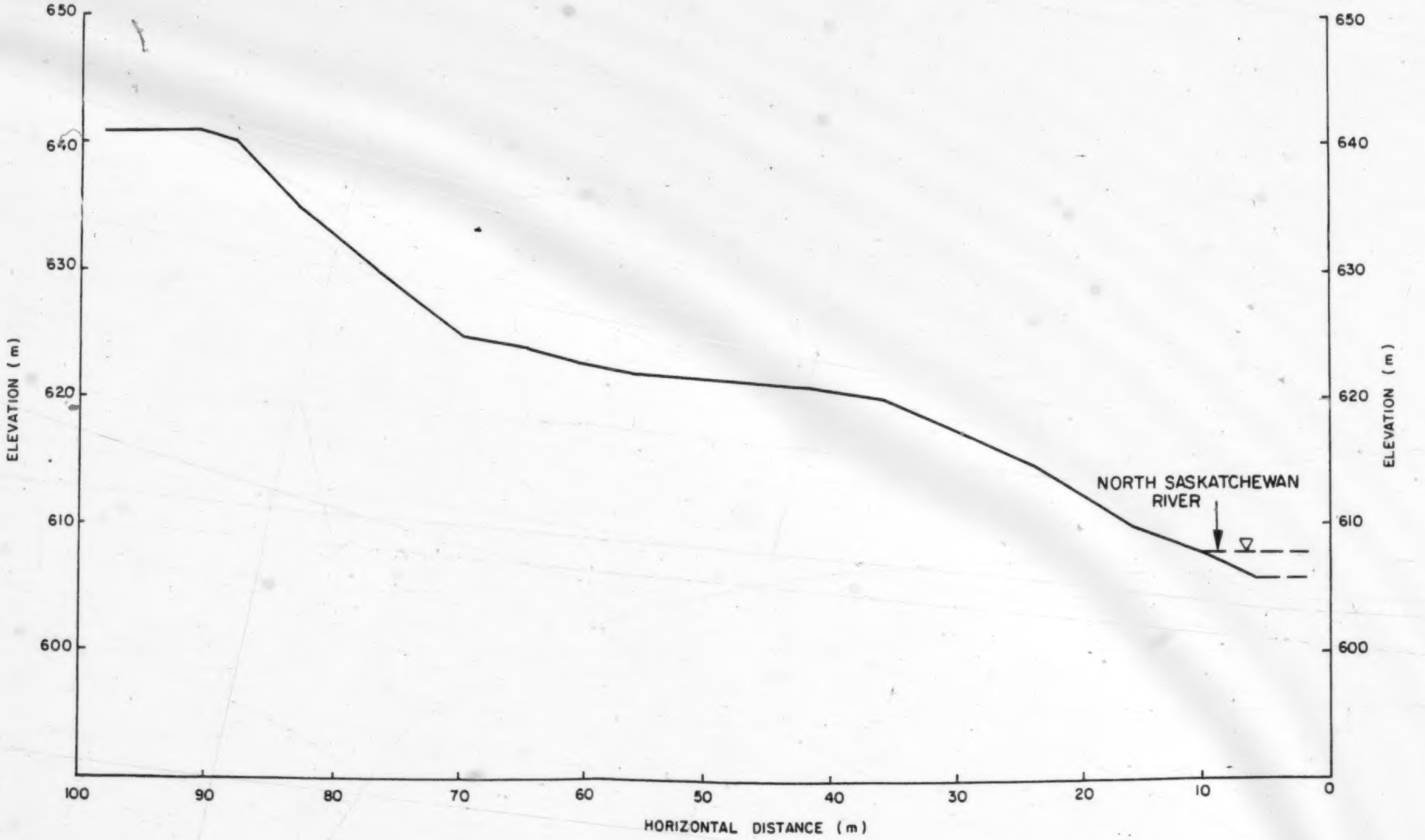
MICROFILM DATE

NOTE:
PROFILE CONSTRUCTION FROM 1:5000 CONTOUR MAP (CADASTRAL NUMBER 940+48)



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Alberta ENVIRONMENT	DESIGN AND CONSTRUCTION DIVISION	NORTH SASKATCHEWAN RIVER SLOPE STUDY PROFILE OF SLOPE MOVEMENT SM-F3
SUBMITTED	DESIGNED	
DATE	CHECKED	
APPROVED	DRAWN	SCALE AS SHOWN · SHEET 1 OF 1
DATE	CHECKED /	DATE JUNE 1986 · FIGURE 84

P3-280x430

comprised of rotated blocks separated by transverse ridges and tension cracks. Drainage down the main body is influenced by the disrupted surface. At the toe of SM-F1 the main body ends abruptly in a steep slope at 7.5 to 10 m above river level. Displaced overburden material is exposed in this unvegetated face. At the base of this slope, fill has been placed on the floodplain probably in an attempt to inhibit river erosion.

The rotated blocks of the main body indicate rotational movement while their distorted nature suggests a downslope change to translational movement. The displaced overburden material exposed on the lower slope indicates the rupture surface is below river level possibly along the overburden-bedrock contact.

Slope movements SM-F2 and SM-F3 have similar features to SM-F1. Profiles of these movements constructed from 1:5000 contour maps (Cadastral Numbers 940+44 and 940+48) show that SM-F2 has a height of 37 m and an average inclination of 24 degrees while SM-F3 has a height of 33 m and an average inclination of 25 degrees (Table 5; Figures 81, 84). Their linear main scarps appear to have sharp margins along the crown and lateral flanks. The scarp faces are sparsely vegetated with grasses and shrubs. The main bodies are densely treed and appear to be comprised of rotated blocks. In both movements the main bodies have an unvegetated downslope face which extends to river level. These features which are similar to those of SM-F1 indicates that

SM-F2 and SM-F3 also underwent compound rotational-translational movement along a rupture surface below river level.

Slope movements SM-F1, SM-F2 and SM-F3 all appear on the 1924 airphotos and have remained dormant over the past 60 years. For SM-F1 the sparsely vegetated main scarp with fairly sharp margins, the well-defined disrupted surface of the main body which influences the downslope drainage indicates an inactive-young age class. The same age class is also assigned to SM-F2 and SM-F3.

4.4 Tributary Creek Valley Slope Movements

Slope movements along the tributary creek valleys fall into two groups, active slope movements on the lower half of undercut slopes along the outside of meanders and older inactive-mature slope movements which extend up to the valley crest. These movements are outlined on Figures 104 to 107 and 110 in Appendix 1. Profiles of the Horsehills Creek, North Creek, Oldman Creek, Pointe-aux-Pins Creek and Ross Creek valleys, constructed within 1 km of the North Saskatchewan River are shown on Figures 85 to 89 respectively.

Prominent examples of the active slope movements occur along the Horsehills Creek valley in SE4-54-23-W4 within 0.5 km of the river valley (Figures 55, 105 and 106). A profile constructed from a 1:5000 contour map (Cadastral Number 943+48) at this location shows the creek valley slopes to be 25 to 28 m high with average inclinations of 31 to

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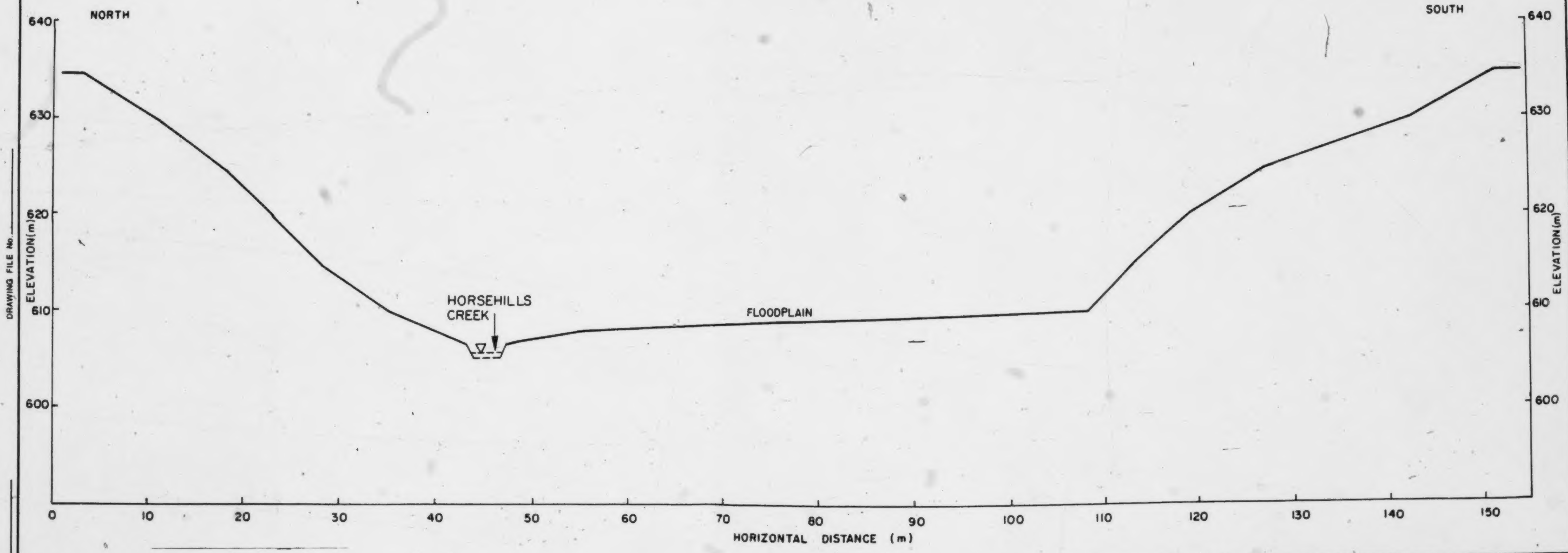
NOTE:

PROFILE CONSTRUCTED FROM 1:5000 CONTOUR MAP (CADASTRAL NUMBER 943+48)



Alberta ENVIRONMENT	DESIGN AND CONSTRUCTION DIVISION	NORTH SASKATCHEWAN RIVER SLOPE STUDY
SUBMITTED DATE	DESIGNED CHECKED	HORSEHILLS CREEK VALLEY PROFILE (~120 m UPSTREAM FROM NORTH SASKATCHEWAN RIVER VALLEY) SE 4-54-23-W4
APPROVED DATE	DRAWN CHECKED	SCALE AS SHOWN DATE JUNE 1986
		SHEET 1 OF 1 FIGURE 85

P3-280x430

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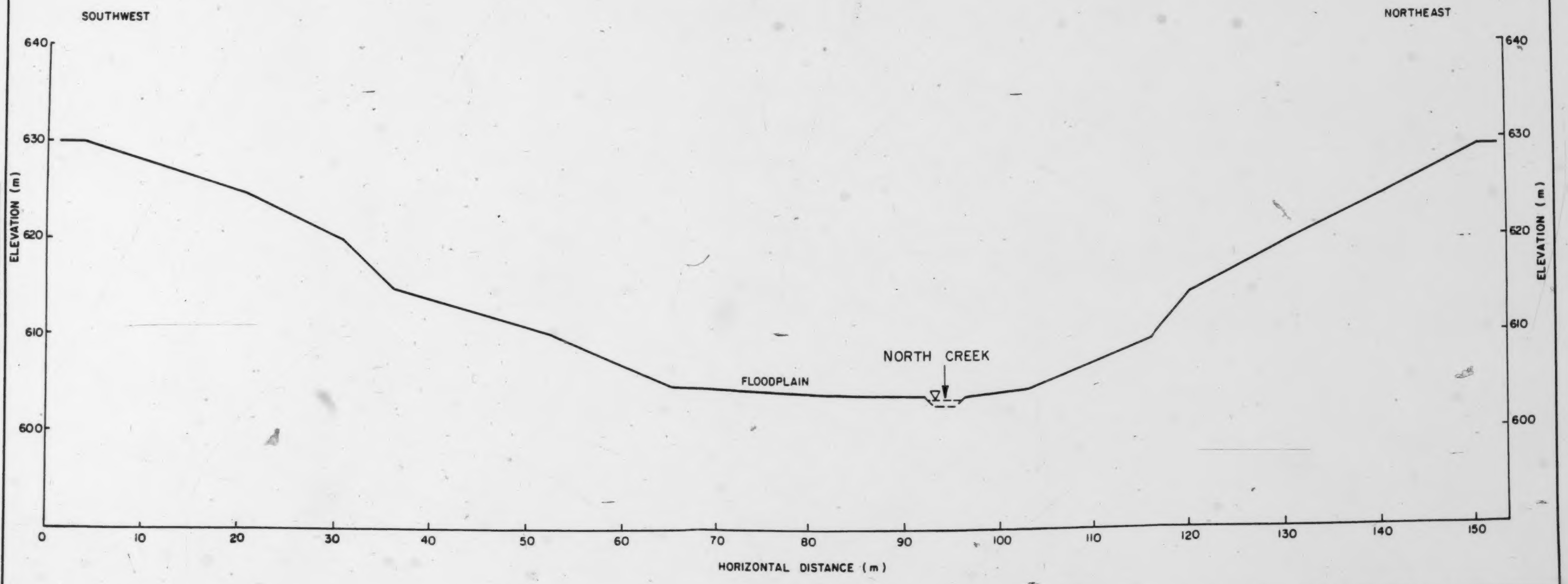
MICROFILM DATE

NOTE:
PROFILE CONSTRUCTED FROM 1:5000 CONTOUR
MAP (CADASTRAL NUMBER 949+52)



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DESIGN AND CONSTRUCTION DIVISION

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

NORTH CREEK VALLEY PROFILE
(~50 m UPSTREAM OF NORTH SASKATCHEWAN
RIVER VALLEY) SE 26-54-23-W4

SCALE AS SHOWN	SHEET 1 OF 1
DATE JUNE 1986	FIGURE 86

P3-280x430

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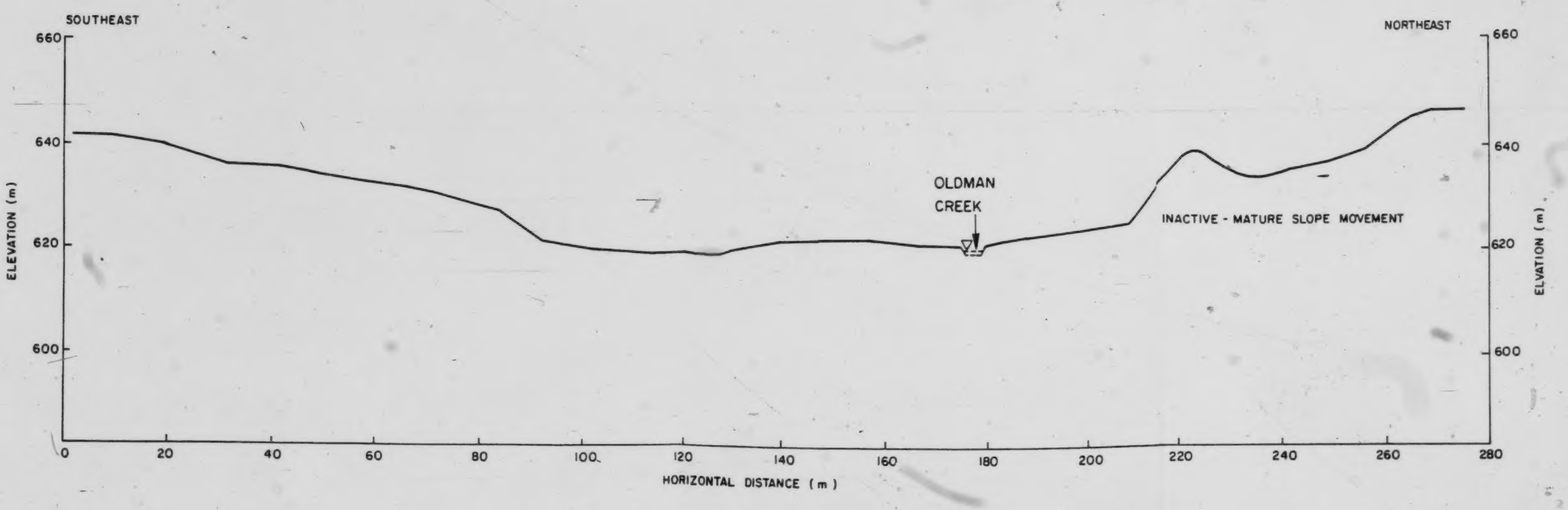
MICROFILM DATE

NOTE:

1. PROFILE CONSTRUCTED FROM 1:5000 CONTOUR MAP (CADASTRAL NUMBER 940+48)



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Alberta ENVIRONMENT	DESIGN AND CONSTRUCTION DIVISION	NORTH SASKATCHEWAN RIVER SLOPE STUDY	
		OLDMAN CREEK VALLEY PROFILE (~850 m UPSTREAM OF NORTH SASKATCHEWAN RIVER VALLEY) SW 26-53-23-W4	
SUBMITTED	DESIGNED		
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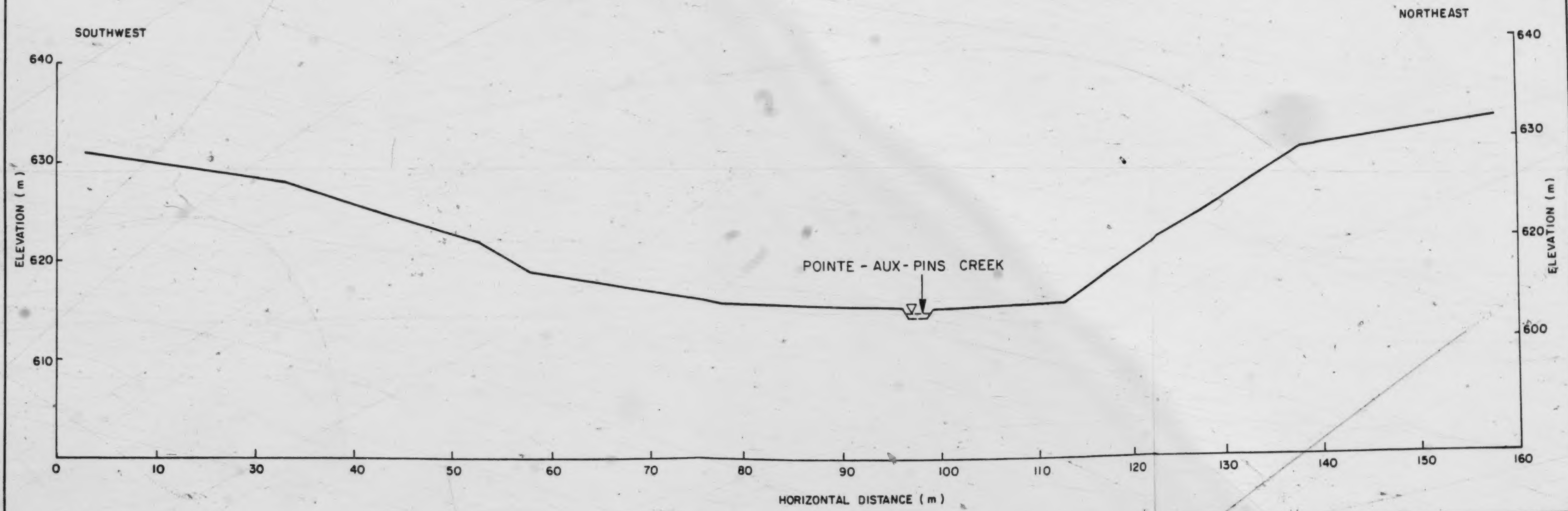
APPROVED	DRAWN	SCALE AS SHOWN	SHEET 1 OF 1
DATE	CHECKED	DATE JUNE 1986	FIGURE 87

P3-280x430

MICROFILM DATE

NOTE:
PROFILE CONSTRUCTED FROM 1:25000
TOPOGRAPHY MAP (NTS 83H/11F)



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DESIGN AND CONSTRUCTION DIVISION

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

POINTE - AUX - PINS CREEK VALLEY PROFILE
(~420 m UPSTREAM FROM NORTH SASKATCHEWAN
RIVER VALLEY) SW 1-54-23-W4

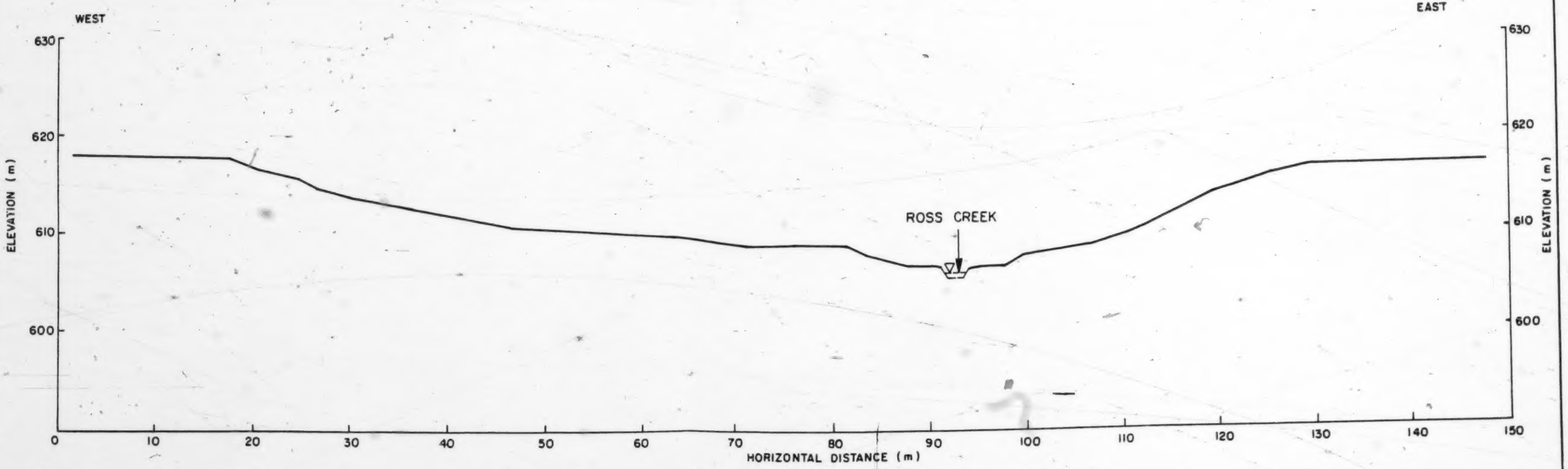
SCALE AS SHOWN	SHEET 1 OF 1
DATE JUNE 1986	FIGURE 88

P3-280x430

170

MICROFILM DATE

NOTE:
PROFILE CONSTRUCTED FROM 1:5000 CONTOUR MAP (CADASTRAL NUMBER 952+56)



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NORTH SASKATCHEWAN RIVER SLOPE STUDY

ROSS CREEK VALLEY PROFILE

(~350m UPSTREAM FOR NORTH SASKATCHEWAN RIVER VALLEY) RIVER LOT 5-FT.SASKATCHEWAN

SCALE AS SHOWN
DATE JUNE 1986
SHEET 1 OF 1
FIGURE 69

P3-280x430

40 degrees (Table 6; Figure 85). On the lower half of these slopes the active movements have steep unvegetated scarps which extend down to mounds of displaced overburden material at the toe. These movements appear to be shallow translational slides initiated by a lack of support at the toe due to creek erosion.

Outlines of the older inactive-mature slope movements are visible on the generally south facing slopes of Horsehills Creek, North Creek Oldman Creek and Pointe-aux-Pins Creek valley slopes. The predominant feature of these movements are arcuate main scarps with rounded margins which connect in series to form the valley crest (Figures 104 to 107). The scarp faces are smooth and vegetated with grasses and shrubs. Usually a mound of displaced material is discernable at the toe of these movements. The surface of these mounds is rounded and vegetated with grasses, shrubs and a few mature trees. Similar movements probably exist on the north facing slopes of the creek valleys but a dense tree cover makes their identification difficult.

As indicated by a review of older airphotos dating back to 1924 the active translational slides have been the only noticeable slope movement activity along the creek valleys. The inactive-mature movements have remained dormant for at least the past 60 years.

4.5 Summary

The most common type of slope movement identified in the study area is translational slides followed in frequency of occurrence by compound rotational- translational movements and flow movements (Table 4). Shallow translational slides occur throughout the study area and involves the downslope sliding of blocks of overburden soils which have separated from the main scarp. This type of movement is represented by SM-A2, SM-B4, SM-D1, SM-D3 to SM-d5, SM-D7 and Sm-d9. The formation of the blocks in the main scarp prior to movement is evidenced by the curvilinear fractures exposed in the left flank of SM-D1. A potential mechanism for actual block separation has been described by Ruban and Thomson (1983) in their slope movement study along the Oldman River. They noted that free water can infiltrate such cracks resulting in higher moisture contents in the adjoining soils and with several annual freeze-thaw cycles a deterioration in shear strength along the fracture. Eventually, gravity overcomes the reduced shear strength and the block separates.

In the study area the amount of valley crest regression resulting from these movements depends on the size of block which separates from the main scarp as illustrated at the top of SM-D3 (Figure 58). This in turn is related to the fracture spacing in the crown area. Downslope sliding of the blocks is aggravated by the steepness of the slopes which range from 30 degrees in Slope Movement Area D to 45 degrees in Slope Movement Area A.

In the Slope Movement Areas A and D there is an absence of deep-seated movements with a rupture surface near river level, even though the slopes are steeply inclined at 30 to 45 degrees. A common characteristic of these slopes is that their lower half is comprised of 10 to 17 m of Saskatchewan sand and gravel which extends below river level (Figures 18 and 64). The occurrence of these sediments may provide a stabilizing effect due to their very dense nature as indicated by Standard Penetration Tests (SPT) in borehole BH-A2 and their permeable nature which provides underdrainage as indicated by seepage areas along the toe of the slopes in these areas (Figures 12, 13 and 62).

Deep-seated translational slides in the study area are confined to SM-E1, SM-E3 and SM-E4 at the upstream end of Slope Movement Area E (Table 4). Based on the detailed investigation by Thomson (1971) of SM-E1 (Lesueur Landslide), which provided a well-documented comparison for SM-E3 and SM-E4, these movements have a roughly horizontal rupture surface at river level along a weak plane in the bedrock strata. As observed by Thomson (1971) the displaced material moved out along a planar rupture surface and cantilevered into the river. He noted that river erosion played a significant role in initiating this movement due to progressive removal of a small terrace and repeated unloading at the toe of the slope. The ongoing effect of this erosion is evident from a review of airphotos dating back to 1950 which shows a gradual removal of displaced material from the toes of SM-E3 and SM-E4 which previously occurred and from the toe of SM-E1 after it occurred in 1963.

Compound rotational-translational movements are almost as common as translational slides in the study area (Table 4). Compound movements include SM-B3, SM-C4 to SM-C9 and SM-F1 to SM-F3. Distinguishing post movement geomorphic features is the occurrence of a shallow depression along the base of the main scarp formed by a gentle backslope surface of the main body. This feature is best shown by the profiles of SM-C5 and SM-F1 (Figures 42 and 80). As well, the surface of the main body is highly disrupted with several individual blocks which have undergone rotational movement as shown by the profiles of SM-C6 and SM-C7 (Figures 46 and 49). In these movements the translational component of movement is usually represented by the distorted bulge of displaced material into the river which distinctly occurs at the toes of SM-C5, SM-C6 and SM-C7.

In the compound rotational-translational movements the rupture surface appears to have three occurrences. Slope movements SM-C4, SM-C6 and SM-C8 have a rupture surface along the overburden-bedrock contact at approximately half the slope height. Slope movements SM-F1, SM-F2 and SM-F3 have a rupture surface probably along the overburden-bedrock contact at 1 to 2 m below river level and slope movements SM-C5, SM-C7 and SM-C9 appear to have a rupture surface in the bedrock strata less than 2 m below river level.

In both the deep-seated translational slides and compound rotational-translation movements which have occurred along weak planes in the bedrock strata, the rupture surface is always at or just below river level as indicated by exposures of displaced bedrock material at toes of SM-B3, SM-C5, SM-C7, SM-C9, SM-E1, SM-E3 and SM-E4 . This occurrence is probably in part related to the effect of lateral river erosion in perpetuating the development of the rupture surface as erosion is actively occurring along the toe of these movements (Figures 44 and 54). Identified rupture surfaces in the bedrock strata occur in layers of bentonitic shale as found by Thomson (1971) in SM-E1 and along thin layers of bentonite less than 100 mm in thickness as exposed in the toe of SM-E7 (Figure 6).

The occurrence of flow movements in the study area is related to the uncontrolled discharge of water down the slope from seepage areas or run-off (Table 4). The seepage discharges from permeable layers or lenses primarily in the overburden soils which provide a contrast in permeability to interrupt the downward movement of groundwater. These permeable units include sandy glaciolacustrine sediments, sand lenses in the till and Saskatchewan sand and gravels overlying bedrock as illustrated by SM-D8, SM-C1 and SM-E12 respectively (Figures 30 and 66). As well, the flow movements associated with gullies eroded by run-off usually have seepage areas on their lateral flanks such as in SM-C3 and SM-E6 (Figures 37 and 74).

Except for SM-D6, the flow movements in the study area occur on slopes below homesteads and farmsteads and their initiation usually coincided with the construction of the buildings on the uplands (Figures 27, 35, 65, 72 and 75). This ~~is~~ evidence for one significant effect of urban development which has already occurred in the study area.

The only active movements mapped along the tributary creek valleys are shallow translational slides involving the surficial layer of slope material. These are all occurring along the outside of meanders in the creeks indicating some degree of lateral erosion. However, a review of the airphotos dating back to 1924 indicates the rate of lateral creek erosion is negligible as the configuration of the valleys has essentially remained unchanged with an absence of any deep-seated movements having occurred for at least the past 60 years.

CHAPTER 5

SET-BACK GUIDELINES

5.1 Previous Work

Set-back guidelines have been established along river valleys through urban centres and around reservoirs where slope movements may potentially result in damages to existing and future development. Harris (1980) summarized the state of legislation in urban centres across Canada regarding restrictions and set-back requirements for the development of land near river valleys. He noted that in most cases the need for set-back requirements resulted from the city, or regulatory body, having to pay compensation for damages caused by slope movements. Historical examples of this situation and the resulting development of set-back policies are described by Trow and Skinner (1980) for North York in Metropolitan Toronto, by Townsend and Thomson (1980) for Edmonton and by Stepanek and Rodier (1980) for Calgary.

For specific sites, these policies have required that a geotechnical slope stability investigation be performed to establish set-back guidelines (Harris 1980). In particular, Edmonton's Top-of-the-Bank Road Policy and Calgary's Slope Stability Policy allow for this type of investigation. To accommodate Edmonton's policy, Townsend and Thomson (1980) outlined an investigative procedure to assess the slope stability conditions and establish a set-back line using theoretical analyses. Their procedure began with a review of available geological literature and geotechnical reports followed by a borehole investigation and geomorphological field examination of the slopes. A computer aided slope stability analysis was then performed based on the slope data gathered and soil and bedrock strength parameters obtained from laboratory testing of borehole samples. To compensate for the effect of development, Townsend and Thomson (1980) also recommended that the level of the groundwater table used in the analysis be 3m above the observed level. The stability of a typical slope was then determined with regard to developing a set-back based on theoretical positions of a rupture surface. They also recommended that a minimum set-back of 4 m be applied to provide access and a buffer zone for unpredicted changes in slope conditions that may be imposed by a development.

A significant effect of urban development on the slope conditions has been described by Hamilton and Tao (1977) where after 15 years of artificial watering of landscaped property at the University of Saskatchewan, a 2 to 6 m rise in the groundwater table was recorded. In other reports by R.M. Hardy and Associates Ltd. (1974, 1975a, 1975b), EBA Engineering Consultants Ltd. (1973), Mackay and Thomson (1980) and Ruban and Thomson (1983) dealing with slope stability conditions, it was mentioned that a rise in the groundwater table could result from leaky storm sewers, irrigation systems, water reservoirs such as swimming pools and dug outs and from weeping tile fields located adjacent to the slope.

The reports by R.M. Hardy and Associates Ltd. (1974, 1975a, 1975b) summarized the geotechnical slope stability investigations and development of a set-back for three residential areas along the North Saskatchewan River within Edmonton. These included the Clareview Subdivision, Glamorgan Heights and South Westridge Subdivision. EBA Engineering Consultants Ltd. (1973) performed a geotechnical slope stability investigation to establish set-back guidelines along the North Saskatchewan River valley for the Pineview Subdivision in River Lots 15 and 17 in Fort Saskatchewan .

In other urban areas such as Lethbridge, Hardy Associates (1978) Ltd. (1983) established set-back guidelines for a 10km stretch of Urban Parks along the Oldman River and tributary creek valleys. Their set-back guidelines were developed from a geotechnical slope stability investigation but with extensive reference to available geological literature and previous slope movement studies for the area. Their resulting guidelines were presented in relation to slope inclination and valley depth and included a minimum set-back of 8m to provide access and maintain a strip of natural vegetation. As well, a site specific geotechnical investigation was deemed mandatory where there was obvious evidence of a slope movement.

Hardy Associates (1978) Ltd. (1984) also established top-of-the-escarpment set-back guidelines for the land adjacent to the South Saskatchewan River and tributary creek valleys through Medicine Hat. In this study the valley slopes were divided into Design Sectors based on stratigraphic and groundwater conditions. For each Design Sector, typical profiles were subjected to slope stability analyses to establish the set-back guidelines. The resulting guidelines were reported in relation to slope inclination and valley depth.

Preliminary set-back guidelines have also been established on an empirical basis with airphoto and field examination of existing slope movement conditions. Mollard (1981) performed this type of study to predict bluff retreat around the Choiceland and Forks Reservoir in Saskatchewan. In dealing with the re-activation of existing movements by toe erosion from wave action, he assumed that new cracks will develop on the upland, a distance back from the existing or youngest mainscarp approximately equal to previous regressions associated with the movement. On this basis, Mollard (1981) established a minimum, maximum and common range of regressions associated with common types of slope movements and stratigraphy around operating reservoirs and natural lakes.

Preliminary set-back guidelines along the Oldman River and tributary coulees through Lethbridge were established on the basis of airphoto and field examination by Ruban and Thomson (1983). They attempted to establish a set back based on estimated valley crest regression of active slope movements. Since there was an absence of slope movement activity along the river valley since 1950, Ruban and Thomson (1983) recommended a conservative "rule-of=thumb" set-back equal to the valley depth to accommodate the potential effect of future development. In contrast, they found that the stability of the coulee slopes was sensitive to minor changes in loading conditions and groundwater table fluctuations induced by man's activities. Hence, they recommended that future development around the coulees be severely restricted and controlled. Their recommendations included: the construction of a perimeter road along the top of the slopes between the heads of adjacent coulees; detailed geotechnical slope stability investigations on a site specific basis; control measures to restrict run-off down the slopes and the addition of water into the slopes through watering of lawns, irrigation of adjacent farmlands, leakage from sewers and watermains or from water reservoirs such as swimming pools, dugouts.

Mackay and Thomson (1980) performed an airphoto and field examination of slope movements to establish preliminary set-back guidelines along the South Saskatchewan River and tributary creek valleys through Medicine Hat. They divided the river valley into two sections based on stratigraphy, geomorphology and slope movement types. For a 15 km reach of the river valley where the slopes were primarily comprised of bedrock, they recommended a "rule of thumb" set-back based on a single worst case slope movement known as the Power Plant Slide. As this slope movement had caused an amount of valley crest regression approximately equal to 80% of the slope height, a set-back of 1.5 to 2 times the slope height was recommended. In the remaining 16.5 km to 17 km reach of the river valley in their study area the slopes were comprised of interbedded tills and sands, and groundwater seepage was found to be a significant factor in initiating slope movements. As seepage pressures act independently of slope height, Mackay and Thomson (1980) recommended that set-back guidelines be established on a site specific basis with a geotechnical slope stability investigation.

A theoretical approach to predicting long term slope degradation as a basis for predicting bluff retreat was explained by Vallejo and Edil (1979) in their study of the shoreline around the Great Lakes. Vallejo and Edil (1979) based their work on the concept of an ultimate angle of stability explained as follows:

> "for natural slopes in clay material there is a single angle above which rapid mass movements will from time to time occur and below which the slope material is stable with respect to rapid mass movements with the exception of slower processes like creep."

Vallejo and Edil (1979) further explained that a natural slope adjusts to geometrical changes through a series of deep-seated movements and shallow slides until the ultimate angle of stability is reached. To establish the ultimate angle of stability, they performed a series of

Simplified Bishop Method slope stability analysis on 10 to 50 m high bluffs comprised of till and glaciolacustrine sediments. From these analyses they produced three sets of design charts which showed that the ultimate angle of stability is only dependent on the effective angle of internal friction and the groundwater pressure conditions, and that it is independent of slope height. Their analyses were based on long term limit equilibrium conditions with a factor of safety equal to one, an effective angle of internal friction at residual and the cohesive component of strength equal to zero due to weathering, and previous movements of the clay slopes.

In the absence of computer aided stability analyses, a theoretical approximation of the ultimate angle of stability can be obtained by applying Infinite Slope Analysis as described by Cernica (1981). For the study area residual angles of shearing resistance of the overburden soils and bedrock comprising the slopes have been reported by Thomson (1971), R.M. Hardy & Associates Ltd. (1976) and Thomson and Yachyshyn (1977). As well, for clayey soils an approximate value can be obtained from a chart developed by Skempton (1985) showing a relationship between residual angle of shearing resistance and percent clay fraction (CF).

The process of long term slope degradation is also discussed by Thomson and Tiedemann (1982) in their report on factors affecting slope movements in urban areas. They referred to previous work by Hutchinson (1975) on cliffs in London Clay that showed after abandonment, slope degradation occurs first through deep-seated rotational movements followed by shallower movements on the upper part of the slope as colluvium collects near the bottom. This degradation continues until a long term final slope or ultimate angle of stability is reached. The amount of time it takes for these cliffs to degrade from an initial slope of 15 to 30 degrees to a long term slope of approximately 8 degrees was shown to be approximately 1000 years after their abandonment.

In his report on the Choiceland and Forks Reservoir, Mollard (1981) also combined the theoretical concept of an ultimate angle of stability and long term degraded slopes to predict bluff retreat. He constructed a summary plot of the design chart data of Vallejo and Edil (1979) to compare the ultimate angles of stability for comparison with measured inclinations of old abandoned slopes along major river valleys in Saskatchewan.

In his prediction of bluff retreat Mollard (1981) also accounted for regression due to beach development and different wave energy environments along the reservoir shorelines. This indicates that lateral river erosion would also have to be considered in predicting slope regression along river valleys. Thomson and Townsend (1979) investigated the lateral erosion rates of the North Saskatchewan River at two locations within Edmonton. Below the University of Alberta they reviewed survey data from 1882 to 1965 and estimated a lateral erosion rate of 15 to 36 m/100 years. They also reviewed survey data from 1883 to 1953 and examined 1953 to 1976 airphotos of the river bank below Strathcona Park. For this location they estimated a lateral erosion rate of 30 to 60 m/100 years. As slope movements had occurred at both locations they considered these rates to represent net erosion. In addition, an estimated rate of net lateral river erosion of 5 to 10 m/50 years was supplied by Fondstad (personal communication, 1985) based on his work experience with the River Engineering Branch of Alberta Environment.

5.2 Development of Set-Back Guidelines

The set-back guidelines established for the study area are based on the concept of the ultimate angle of stability. As explained by Vallejo and Edil (1979) and Mollard (1981) this concept implies that after abandonment, slopes degrade to an inclination at or below which the slope is stable with respect to rapid movements. In contrast, slopes which are being subjected to toe erosion by a river or creek repeatedly undergo movement followed by oversteepening as displaced material at the toe is removed by erosion (Thomson and Tiedemann, 1982). This indicates that the inclination of the oversteepened slopes which are being subjected to river erosion will always be greater than the abandoned slopes which are near their ultimate angle of stability. Comparison of the two profiles provides an estimate of potential long term regression of the oversteepened slopes.

5.2.1 Potential Long Term Regression

Potential long term regression can be estimated by an empirical method of comparing the inclination of the abandoned river valley slopes assumed to be at their ultimate angle of stability to the inclination of oversteepened slopes with similar stratigraphy and groundwater pressure conditions. As shown in Figure 90 this comparison is done by projecting a line representing the ultimate angle of stability up from the toe and taking the difference between the point where this line intersects the upland ground surface and the present position of the valley crest.

Two factors indicate that the abandoned river valley slopes in the study area are probably at their ultimate angle of stability. These slopes occur above and along the outside of the low level terrace in the North Saskatchewan River valley (Figure 1; Appendix 1). With this occurrence the age of these slopes is inferred to be up to 8,000 years old as implied from radiocarbon dates in the low level terraces in Edmonton (Thomson and Townsend, 1979; Thomson and Tiedemann, 1982). This inferred age suggests that sufficient time has elapsed for the abandoned slopes to have degraded to their ultimate angle of stability. As a comparison cliffs in London Clay have been estimated to take 1,000 years to degrade to an a long term final angle of slope (Thomson and Tiedemann, 1982). In addition, there is an absence of slope movements which can be classed as active or inactive-young along the abandoned slopes. Only degraded impressions of inactive-mature slope movements visible on these slopes indicating they are in a stable condition (Figures 101 to 115; Appendix 1).

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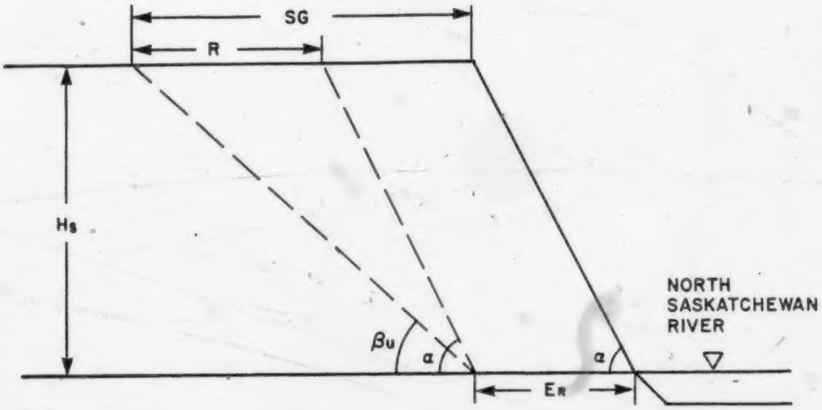

R — POTENTIAL LONG TERM REGRESSION

$$= \frac{H_s}{\tan\beta_u} - \frac{H_s}{\tan\alpha}$$

H_s — SLOPE HEIGHT

β_u — ULTIMATE ANGLE OF STABILITY

α — INCLINATION OF OVERSTEEPENED SLOPE

SG — SET-BACK GUIDELINE

$= R + E_R$

E_R — NET LATERAL RIVER EROSION

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

DETERMINATION OF POTENTIAL LONG TERM REGRESSION AND SET-BACK GUIDELINE

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SHEET 1 OF 1
FIGURE 90

Oversteepened slopes in the study area occur along the river in Slope Movement Areas A to F and along the tributary creek valleys. The stratigraphy and groundwater pressure conditions as previously described in Sections 4.3.1 to 4.3.6 of Chapter 4 provide a basis for three Stratigraphic Categories as follows:

Stratigraphic Category	Groundwater Table (Hw) in Relation to Slope Height (Hs)	Simplified Stratigraphy
1	Hw = 0	Slopes comprised of overburden soils with the overburden - bedrock contact below river or creek level.
2	Hw = 1/2 Hs	Slopes comprised of overburden soils and bedrock strata with the overburden - bedrock contact in the lower half of the slope.
3	Hw = 1/4 Hs	Slopes comprised primarily of bedrock strata with the overburden - bedrock contact in the upper half of the slope.

Based on their simplified stratigraphy Slope Movement Areas A, D and F comprise Stratigraphic Category 1, Slope Movement Areas B and E comprise Stratigraphic Category 2 and Slope Movement Area C comprises Stratigraphic Category 3 (Table 5).

The position of the groundwater table at the bottom of the slopes in Stratigraphic Category 1 is based on field observations of seepage areas and water levels taken in borehole BH-A2 (Table 7; Figures 12, 13 and

18). The lower half of these slopes is comprised of 10 to 17 m of Saskatchewan sand and gravel which underdrains the slope and draws down the groundwater table.

The position of the groundwater table at half the slope height for Stratigraphic Category 2 is a conservative estimate based on the piezometric investigations done by Thomson (1971) in SM-E1 at the upstream end of Slope Movement Area E (Figure 70). The slopes in Stratigraphic Category 2 have less than 6 m of Saskatchewan sand and gravel overlying bedrock at approximately half the slope height.

The position of the groundwater table at a quarter of the slope height for Stratigraphic Category 3 is based on the water levels taken in borehole BH-C1 (Table 7; Figure 28). For the slopes in this category Saskatchewan sand and gravel are absent and up to 7.5 m of till directly overlies bedrock.

The abandoned river valley slopes and the tributary creek valley slopes are included in the Stratigraphic Categories by inference from the nearest segment of a Slope Movement Area. For example the abandoned slopes on the upstream and downstream sides of Slope Movement Area D are inferred to have a similar stratigraphy to the oversteepened slopes in Area D. As well, the stratigraphy of the Horsehills Creek Valley slopes is inferred from Slope Movement Area D in which this creek enters the North Saskatchewan River valley.

For each Stratigraphic Category the inclination of the abandoned slopes are plotted against slope height as shown on Figures 91 to 93. From these plots an empirical estimate of the ultimate angle of stability is obtained from an average of the inclinations. As a comparison, theoretical value for the ultimate angle of stability for different positions of the groundwater table are also shown. These values are approximated from Infinite Slope Analysis (Cernica, 1981) as outlined in Table 8 and extrapolated from a summary plot of the design chart data of Vallejo and Edil (1979) as shown on Figure 94. For the Infinite Slope Analyses the long term parameters used are a residual angle of shearing resistance, a component of cohesive strength equal to zero and a Factor of Safety equal to one. Except for the glaciolacustrine silty clay and sandstone bedrock strata, the residual angles are taken from values published in previous reports (Thomson, 1971; Thomson and Yachyshyn, 1977; R. M. Hardy & Associates Ltd., 1976). For the glaciolacustrine silty clay, Skempton's (1985) relationship between residual angle of shearing resistance and percent clay fraction is used. The percent clay fraction is taken from hydrometer analysis on samples of the clay from boreholes BH-A2 and BH-C1 (Figures 2 and 4). For the sandstone strata, the residual angle shearing resistance is given by a direct shear test performed on a sample from borehole BH-C1 at a depth of 21.20 m. The results of this test are plotted on Figure 95.

The design charts by Vallejo and Edil (1979) consist of three sets of charts with slope inclination plotted against slope height for values of

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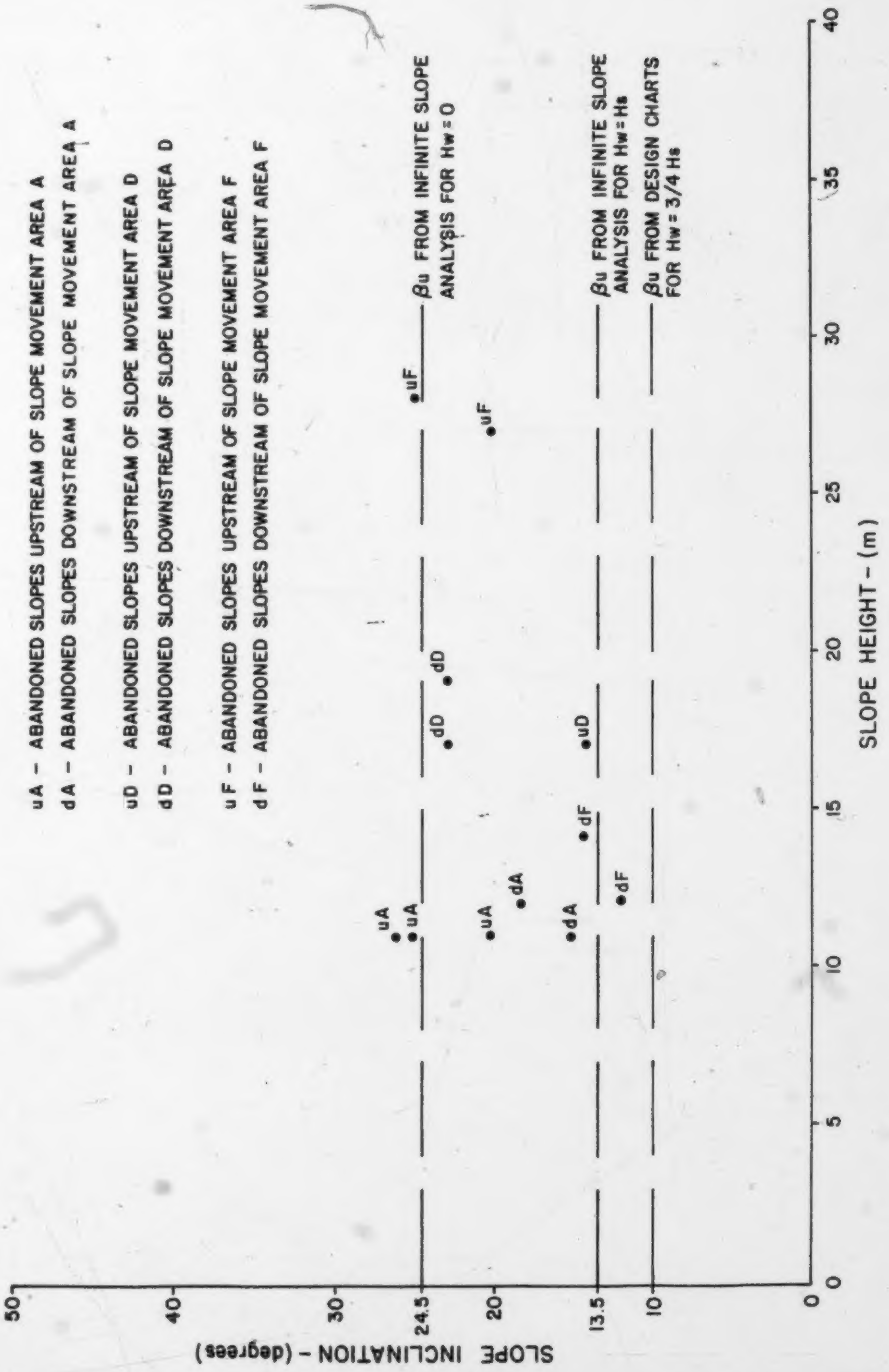

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SUBMITTED	DESIGNED	NORTH SASKATCHEWAN RIVER SLOPE STUDY
DATE	CHECKED	SLOPE INCLINATION VS. HEIGHT FOR ABANDONED VALLEY SLOPES OF STRATIGRAPHIC CATEGORY I
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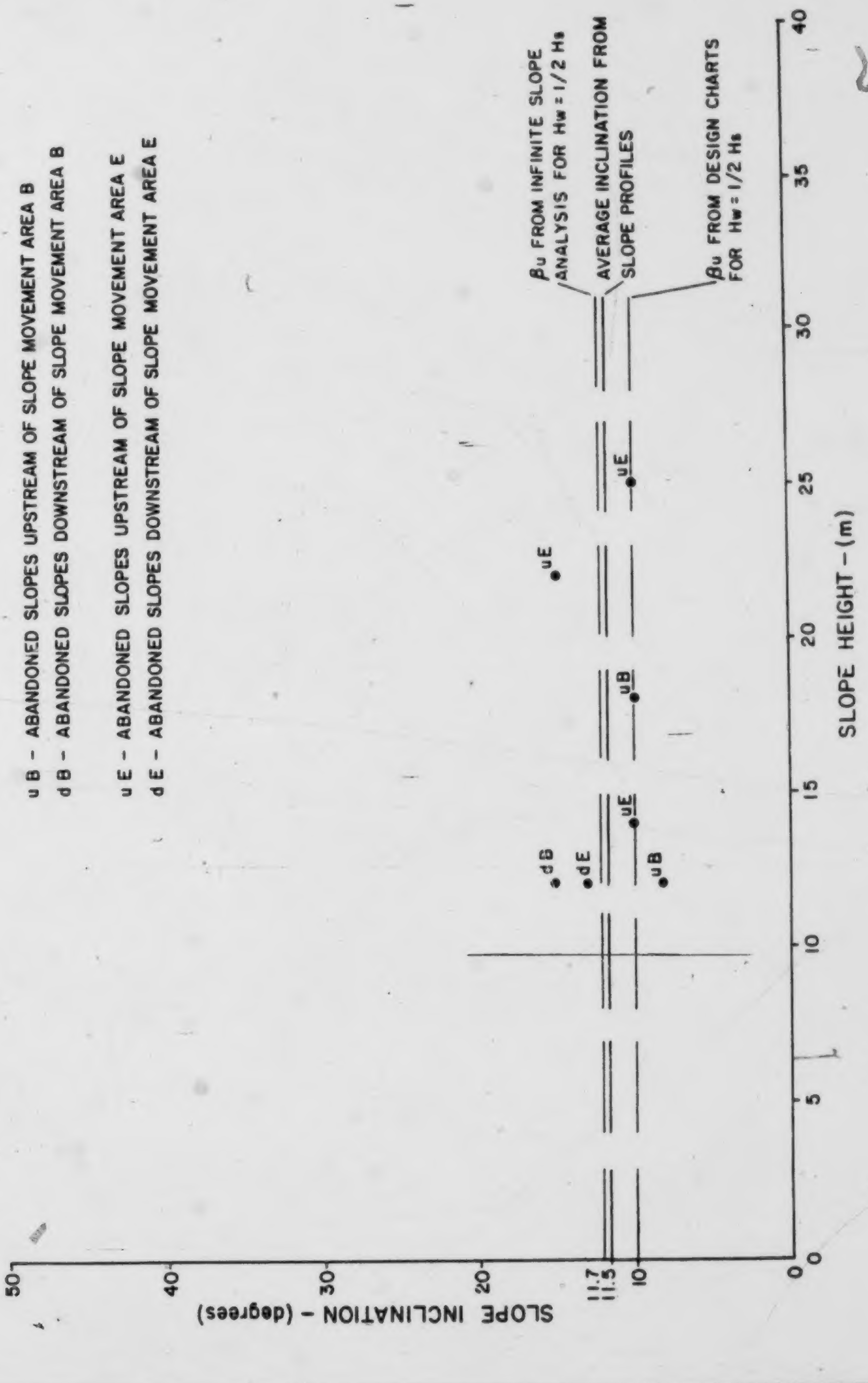

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

SLOPE INCLINATION VS. HEIGHT FOR ABANDONED VALLEY SLOPES OF STRATIGRAPHIC CATEGORY 2

SCALE AS SHOWN	SHEET 1 OF 1
DATE JUNE 1986	FIGURE 92

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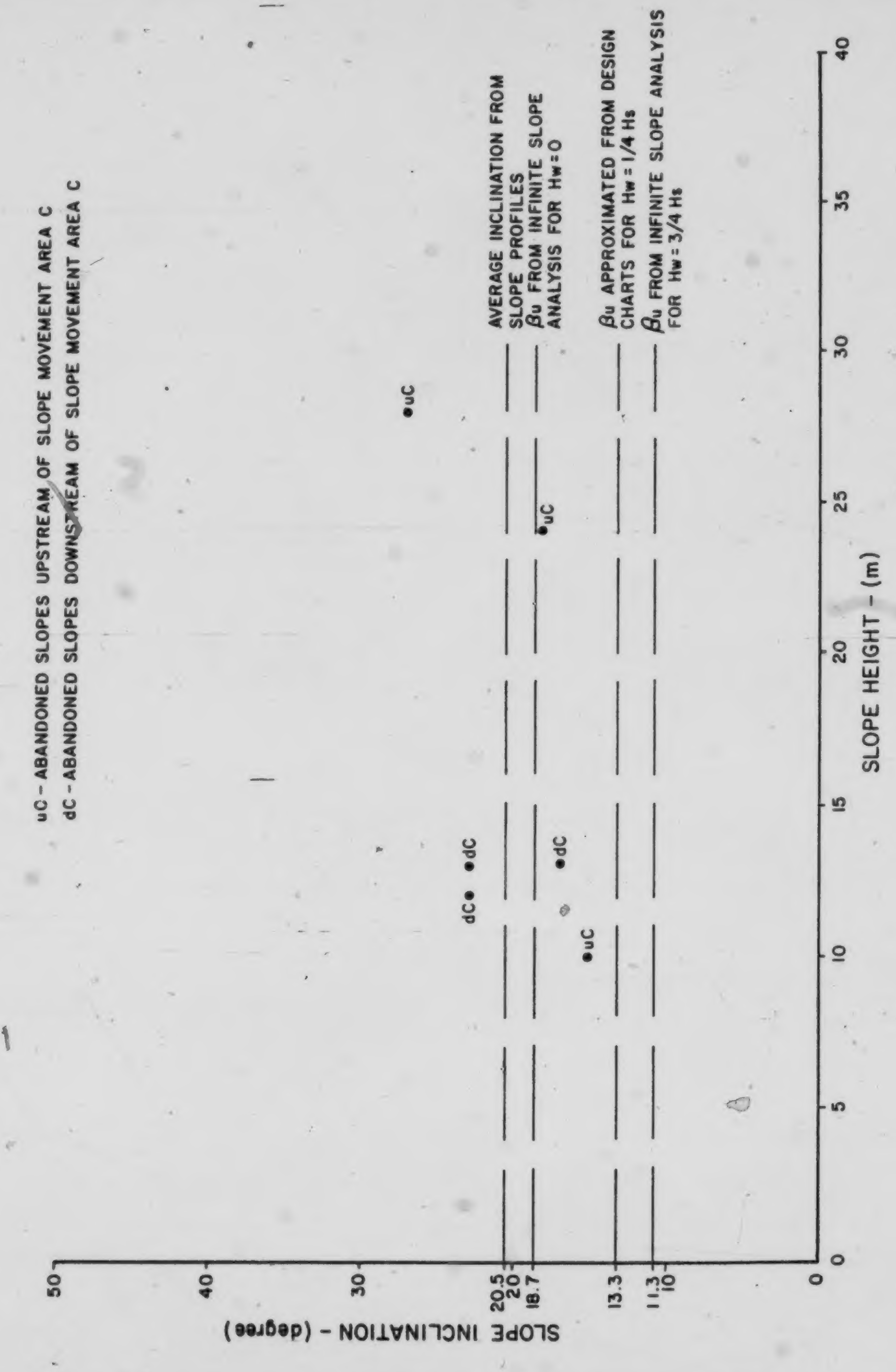

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

SLOPE INCLINATION VS. HEIGHT FOR ABANDONED VALLEY SLOPES OF STRATIGRAPHIC CATEGORY 3

SCALE AS SHOWN	SHEET 1 OF 1
DATE JUNE 1986	FIGURE 93

TABLE 8 - THEORETICAL DETERMINATION OF ULTIMATE ANGLE OF STABILITY (β_u)

1 Stratigraphic Category 1

1.1 Simplified Stratigraphy:

(Upland Ground Surface to North Saskatchewan River Level)

Average Slope Height = 30 m

0 - 3.5 m Silty Clay

3.5 - 16.5 m Clay Till

16.5 - 30 m Sand and Gravel

1.2 Residual Angle of Shearing Resistance (ϕ_R):

Silty Clay PI = 25.3% (BH-A2 & BH-C1)
CF = 43% (BH-A2 & BH-C1)

PI/CF = 0.59

$\therefore \phi_R = 14^{\circ}$ (Skempton, 1985)

Clay Till - $\phi_R = 22.6^{\circ}$ (Thomson, 1971)

Sand and Gravel - $\phi_R = 35^{\circ}$ (Thomson, 1971; R.M. Hardy & Associates Ltd., 1976)

ϕ_{R_w} = average residual angle of shearing resistance for whole slope

$$= \tan^{-1} \frac{30}{3.5/\tan 14^{\circ} + 13/\tan 22.6^{\circ} + 13.5/\tan 35^{\circ}}$$

$$= 24.5^{\circ}$$

1.3 Infinite Slope Analysis:

Groundwater Table at River Level ($H_w = 0$)

$$FS = \frac{\tan \phi_{Rw}}{\tan \beta_u} = 1$$

$\therefore \beta_u = 24.5^{\circ}$

TABLE 8 - THEORETICAL DETERMINATION OF ULTIMATE ANGLE OF STABILITY (Cont'd)

Groundwater Table at Upland Ground Surface ($H_W = H_S$)

$$FS = \frac{\gamma_b \tan\phi_{Rw}}{\gamma \tan\beta_u} = 1$$

$\gamma = 20.50$ KN/m^3 (BH-A2, BH-B1 & BH-C1)

$\gamma_b = (\gamma - \gamma_w)$

$= (20.50-9.81)$

$\therefore \gamma_b = 10.69$ KN/m^3

$$\therefore \beta_u = \tan^{-1}\frac{(10.69 \tan 24.5^o)}{20.50}$$

$= 13.5^o$

2 Stratigraphic Category 2

2.1 Simplified Stratigraphy:

(Upland Ground Surface to North Saskatchewan River Level)

Average Slope Height = 27 m

0.45 m Silty Sand

4.5 - 10.5 m Clay Till

10.5 - 15.5 m Sand and Gravel

15.5 - 27 m Interbedded Clay Shale and Bentonitic Shale

2.2 Residual Angle or Shearing Resistance (ϕ_R):

Overburden Soils:

Silty Sand - $\phi_R = 38^o$ (Thomson, 1971)

Clay Till - $\phi_R = 22.6^o$ (Thomson, 1971)

Sand and Gravel - $\phi_R = 35^o$ (Thomson, 1971; R.M. Hardy & Associates Ltd., 1976)

ϕ_{Rov} = average residual angle of shearing resistance for overburden soils

TABLE 8 - THEORETICAL DETERMINATION OF ULTIMATE ANGLE OF STABILITY (Cont'd)

$$\therefore \phi_{R_{ov}} = \tan^{-1} \frac{15.5}{4.5/\tan 38^{\circ} + 6/\tan 22.6^{\circ} + 5/\tan 35^{\circ}}$$

$$= 29.5^{\circ}$$

Bedrock:

Clay Shale - $\phi_R = 14.5^{\circ}$ (Thomson, 1971;
Thomson and Yacyshyn, 1977)

Bentonitic Shale - $\phi_R = 9^{\circ}$ (Thomson, 1971;
Thomson and Yachyshyn, 1977)

ϕ_{R_b} = average residual angle of shearing resistance for bedrock strata

$$= \frac{14.5^{\circ} + 9^{\circ}}{2}$$

$$= 11.8^{\circ}$$

ϕ_{R_w} = average residual angle of shearing resistance for whole slope

$$= \tan^{-1} \frac{27}{15.5/\tan 29.5^{\circ} + 11.5/\tan 11.8^{\circ}}$$

$$= 18.1^{\circ}$$

2.3 Infinite Slope Analysis:

Groundwater Table at Overburden-Bedrock Contact ($H_w = 1/2\ H_s$)

For Lower Half of Slope Comprised of Bedrock

$$FS = \frac{\gamma_b \tan \phi_{R_b}}{\gamma \tan \beta_{u_b}} = 1$$

β_{u_b} = ultimate angle of stability for the bedrock strata

γ = 21.00 KN/m^3 (BH-B1 & BH-C1)

$\gamma_b = (\gamma - \gamma_w)$

= 11.19 KN/m^3

TABLE 8 - THEORETICAL DETERMINATION OF ULTIMATE ANGLE OF STABILITY (Cont'd)

$$\therefore \beta u_b = \tan^{-1} \frac{(11.19 \tan 11.8^{\circ})}{21.00}$$

$$= 6.4^{\circ}$$

For Upper Half of Slope Comprised of Overburden Soils

$$FS = \frac{\tan \phi_{R_{OV}}}{\tan \beta u_{OV}} = 1$$

βu_{ov} = ultimate angle of stability for the overburden soils

$$= 29.5^{\circ}$$

For Whole Slope

$$\beta u = \tan^{-1} \frac{27}{15.5/\tan 29.5^{\circ} + 11.5/\tan 6.4^{\circ}}$$

$$= 11.7^{\circ}$$

3 Stratigraphic Category:3

3.1 Simplified Stratigraphy:

(Upland Ground Surface to North Saskatchewan River Level)

Average Slope Height = 37 m

0 - 2.3 m Silty Clay

2.5 - 7 m Clay Till

7 - 37 m Interbedded Clay Shale,
Bentonitic Shale and Sandstone

3.2 Residual Angle of Shearing Resistance (ϕ_R):

Overburden Soils:

Silty Clay - PI = 25.3% (BH-A2 & BH-C1)

CF = 43% (BH-A2 & BH-C1)

PI/CF = 0.59

$\therefore \phi_R = 14^{\circ}$ (Skempton, 1985)

TABLE 8 - THEORETICAL DETERMINATION OF ULTIMATE ANGLE OF STABILITY (Cont'd)

Clay Till - $\phi_R = 22.6^\circ$ (Thomson, 1971)

$\phi_{R_{ov}}$ = average residual angle of shearing resistance for the overburden soils

$$= \tan^{-1} \frac{7}{2.5/\tan 14^\circ + 4.5/\tan 22.7^\circ}$$

$$= 18.6^\circ$$

Bedrock:

Clay Shale - $\phi_R = 14.5^\circ$ (Thomson, 1971;
Thomson and Yachyshyn, 1977)

Bentonitic Shale - $\phi_R = 9^\circ$ (Thomson, 1971;
Thomson and Yachyshyn, 1977)

Sandstone - $\phi_R = 33^\circ$ (Direct Shear - BH-C1 @ 21.20 m)

ϕ_{R_b} = average residual angle of shearing resistance for for the bedrock strata

$$= \frac{14.5^\circ + 9^\circ + 33^\circ}{3}$$

$$= 18.8^\circ$$

ϕ_{R_W} = average residual angle of shearing resistance for whole slope

$$= \tan^{-1} \frac{37}{7/\tan 18.6 + 30/\tan 18.8^\circ}$$

$$= 18.7^\circ$$

3.3 Infinite Slope Analysis

Groundwater Table at River Level ($H_w = 0$)

$$FS = \frac{\tan \phi_{R_W}}{\tan \beta_u} = 1$$

$$\therefore \beta_u = 18.7^\circ$$

TABLE 8 - THEORETICAL DETERMINATION OF ULTIMATE ANGLE OF STABILITY (Cont'd)

Groundwater Table at Overburden-Bedrock Contact ($H_W = 3/4\ H_S$)

For Lower Part of Slope Comprised of Bedrock

$$FS = \frac{\gamma_b \tan \phi_{Rb}}{\gamma \tan \beta_{u_b}} = 1$$

β_{u_b} = ultimate angle of stability for the bedrock strata

$\gamma = 21.00$ KN/m^3 (BH-B1 & BH-C1)

$\gamma_b = (\gamma - \gamma_w)$

$= 11.19$ KN/m^3

$$\therefore \beta_{u_b} = \tan^{-1} \left(\frac{11.19 \tan 18.8^o}{21.00} \right)$$

$= 10.3^o$

For Upper Part of Slope Comprised of Overburden Soils

$$FS = \frac{\tan \phi_{Rov}}{\tan \beta_{u_{ov}}} = 1$$

$\beta_{u_{ov}}$ = ultimate angle of stability for the overburden soils

$= 18.6^o$

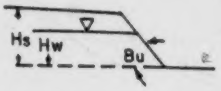
For Whole Slope

$$\beta_u = \tan^{-1} \frac{37}{7/\tan 18.6^o + 30/\tan 10.3^o}$$

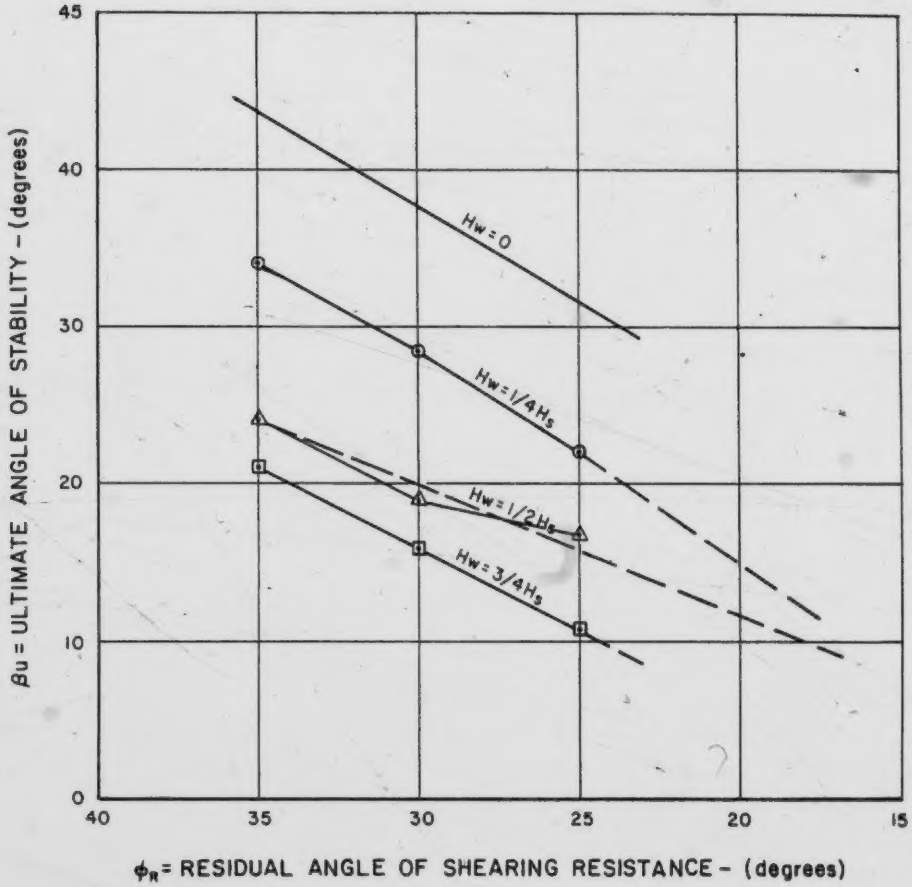
$= 11.3^o$

NOTES: 1. effective cohesion intercept c'=0

2. Hw=0, 1/4H, 1/2H, 3/4H



3. Unit weight, γ = 21KN/m³



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NORTH SASKATCHEWAN RIVER SLOPE STUDY

ULTIMATE ANGLE OF STABILITY VS. RESIDUAL ANGLE OF SHEARING RESISTANCE (MOLLARD, 1981)

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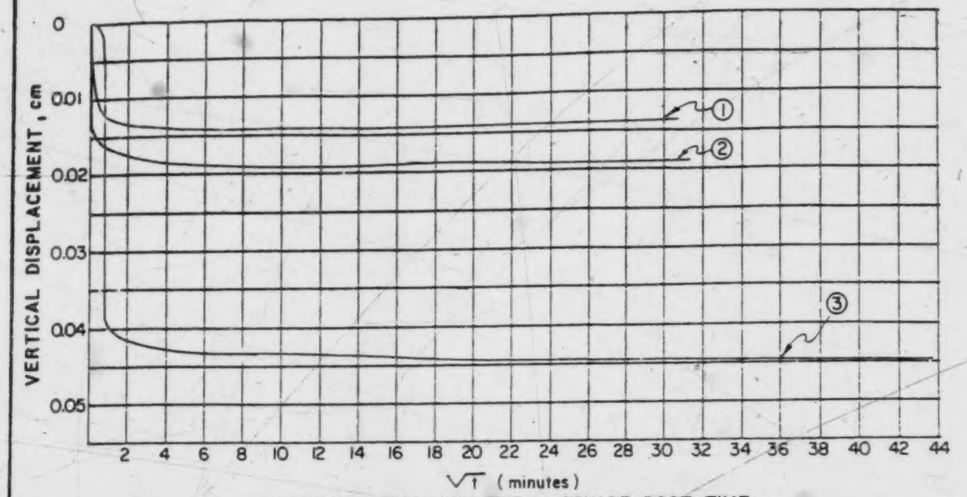
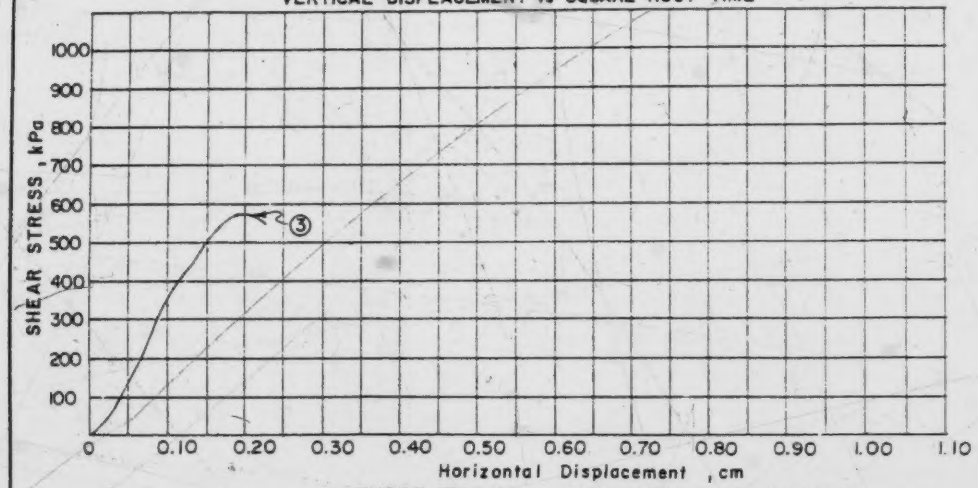
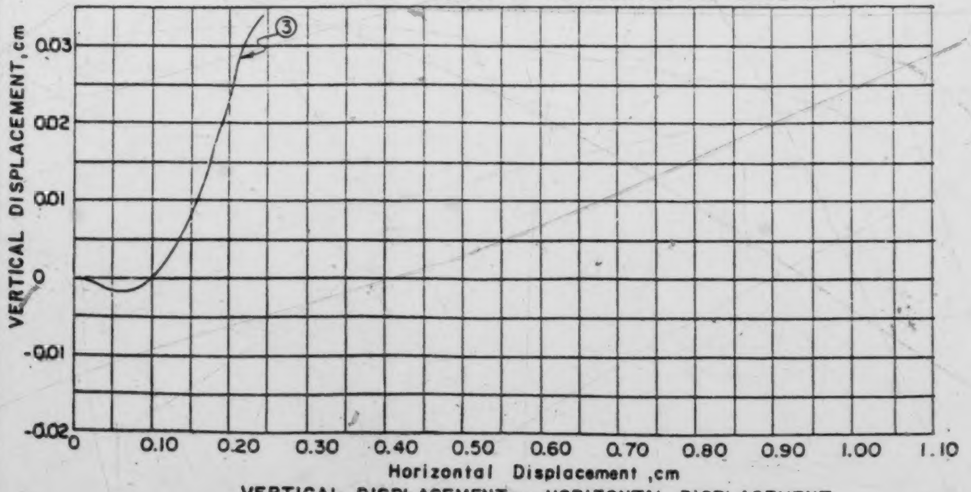


VERTICAL DISPLACEMENT vs SQUARE ROOT TIME

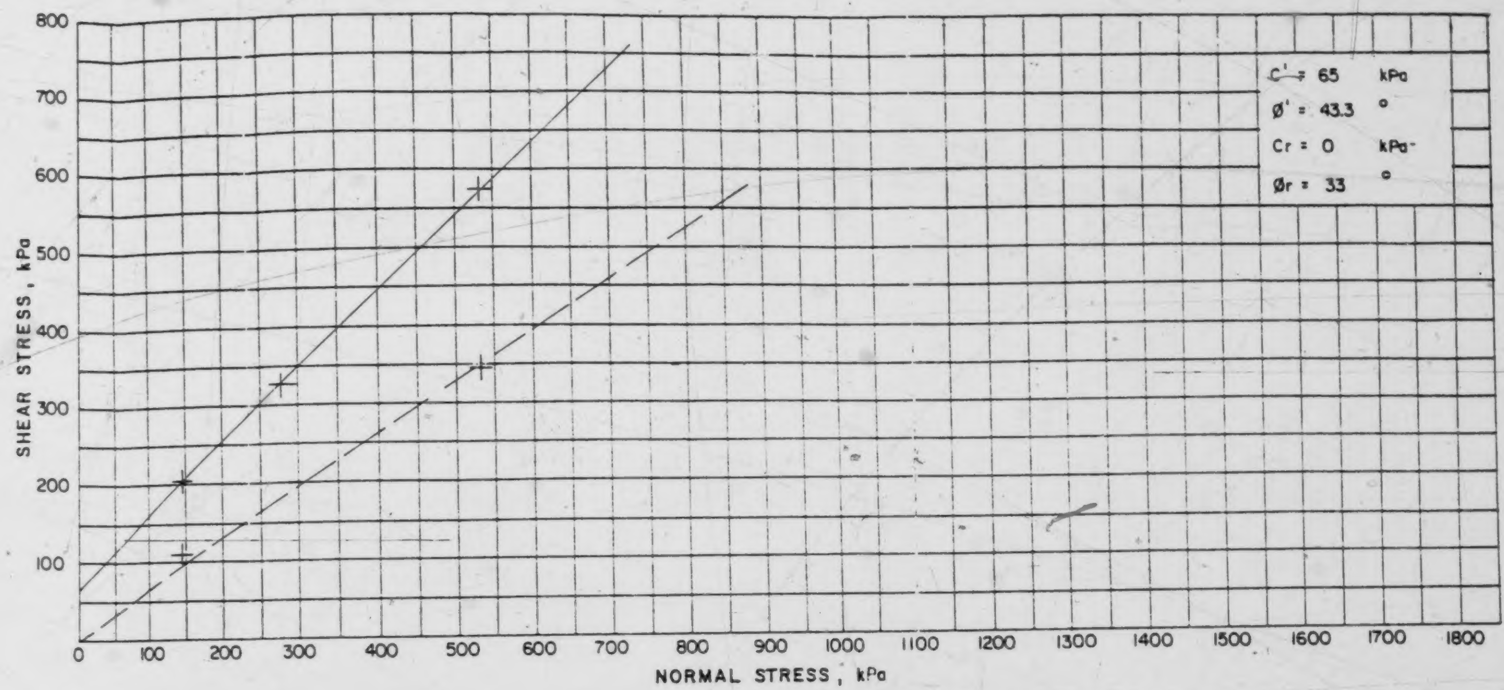


SHEAR STRESS vs HORIZONTAL DISPLACEMENT



VERTICAL DISPLACEMENT vs HORIZONTAL DISPLACEMENT

MATTE 0875



SPECIMEN NUMBER		1	2	3	4	5
EFFECTIVE NORMAL STRESS, kPa.		141.4	277.9	533.2		
BULK DENSITY kg/m³	INITIAL	2019	2137	2106		
	CONSOLIDATED	2034	2159	2157		
	FINAL	—	—	2138		
MOISTURE CONTENT %	INITIAL	10.95	14.16	12.33		
	CONSOLIDATED	10.95	14.16	12.33		
	FINAL	—	—	13.20		
DEGREE OF SATURATION %	INITIAL	59.68	84.23	73.64		
	CONSOLIDATED	60.98	87.00	79.62		
	FINAL			80.71		
RATE OF DISPLACEMENT	CENTIMETERS PER SECOND	← 2 x 10⁻⁶ →				
PEAK SHEAR FAILURE CONDITIONS	EFFECT. SHEAR STRESS, kPa	202.38	325.88	574.83		
	DISPLACEMENT, cm	—	—	0.2000		
RESIDUAL SHEAR FAILURE CONDITIONS	EFFECT. SHEAR STRESS, kPa	105.45	—	340.5		
	DISPLACEMENT, cm.	—	—	7.63		
TEST DETAILS	PEAKS WITH RESIDUALS ON SPECIMEN No.s 1 AND 3.					
REMARKS	SPECIMEN #1, VERTICAL AND HORIZONTAL DISPLACEMENT NOT AVAILABLE. SPECIMEN #2, ONLY PEAK VALUE AVAILABLE.					

SPECIMEN NUMBER		1	2	3	4	5
DIMENSIONS cm	Ht.	1.89	1.89	1.89		
	Dia.	5.08	5.08	5.08		
SPECIMEN TYPE						
ATTERBERG LIMITS, %	w_L		98.6			
	w_P		22.3			
	I_P		76.3			
GRAIN SIZE ANALYSIS, %	SAND		71			
	SILT		10			
	CLAY		19			

SAMPLE DESCRIPTION : SANDSTONE, MED. GRY., F.G., BENTONITIC.

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DESIGN AND CONSTRUCTION DIVISION
GEOTECHNICAL BRANCH
MATERIALS TESTING LABORATORY

NORTH SASKATCHEWAN RIVER

TEST HOLE BH-C1

DEPTH, m 21.20 m (0-850mm)

DIRECT SHEAR TEST

DRAWN BY	DATE JUNE 1986	SHEET 1 OF 1
CHECKED BY	TESTED BY	FIGURE 95

the residual angle of shearing resistance of 25,30 and 35 degrees. In each set there are three charts for positions of the groundwater table at a quarter, a half and three quarters of the slope height. All of the charts have the bulk unit weight (γ) set at 21.00 kN/m^3. These charts are applicable to the study area as samples from boreholes BH-A2, BH-B1 and BH-C1 give average unit weights for the overburden soils of 20.50 kN/m^3 and 21.00 kN/m^3 for the bedrock strata (Figures 2 to 4). In addition, as explained by Vallejo and Edil (1979) the charts can be extrapolated to lower residual angles. Mollard (1981) summarized their chart data as a plot of Ultimate Angle of Stability vs. Residual Angle of Shearing Resistance. This plot is presented as Figure 94 and shows the interpolation lines used to estimate the ultimate angle of stability for slopes in the study area.

Inclinations of the oversteepened slopes in Slope Movement Areas A to F and along the tributary creek valley are plotted against slope height for each Stratigraphic Category as shown on Figures 96 to 100. The ultimate angle of stability selected from the abandoned slope data is plotted on these figures to confirm that these slopes are steeper through repeated movement and subsequent oversteepening.

With the slope height and inclination data from Tables 5 and 6 and the ultimate angles of stability selected from Figures 91 to 93, the potential long term regression is calculated by the equation: $R=Hs/\tan\beta_u - Hs/\tan\alpha$; where R is the potential long term regression; Hs

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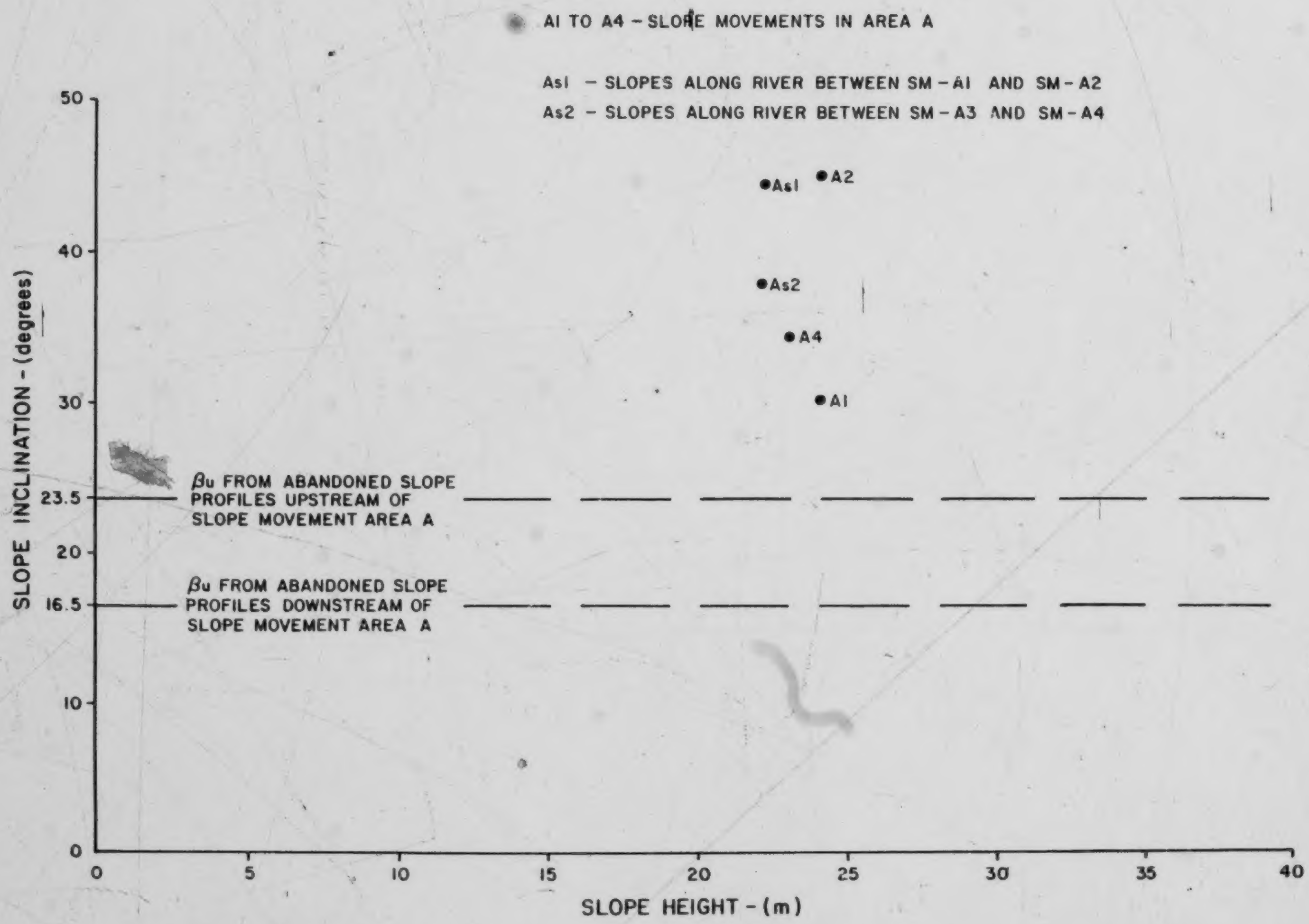

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APPROVED DATE	DRAWN TRACED

NORTH SASKATCHEWAN RIVER SLOPE STUDY

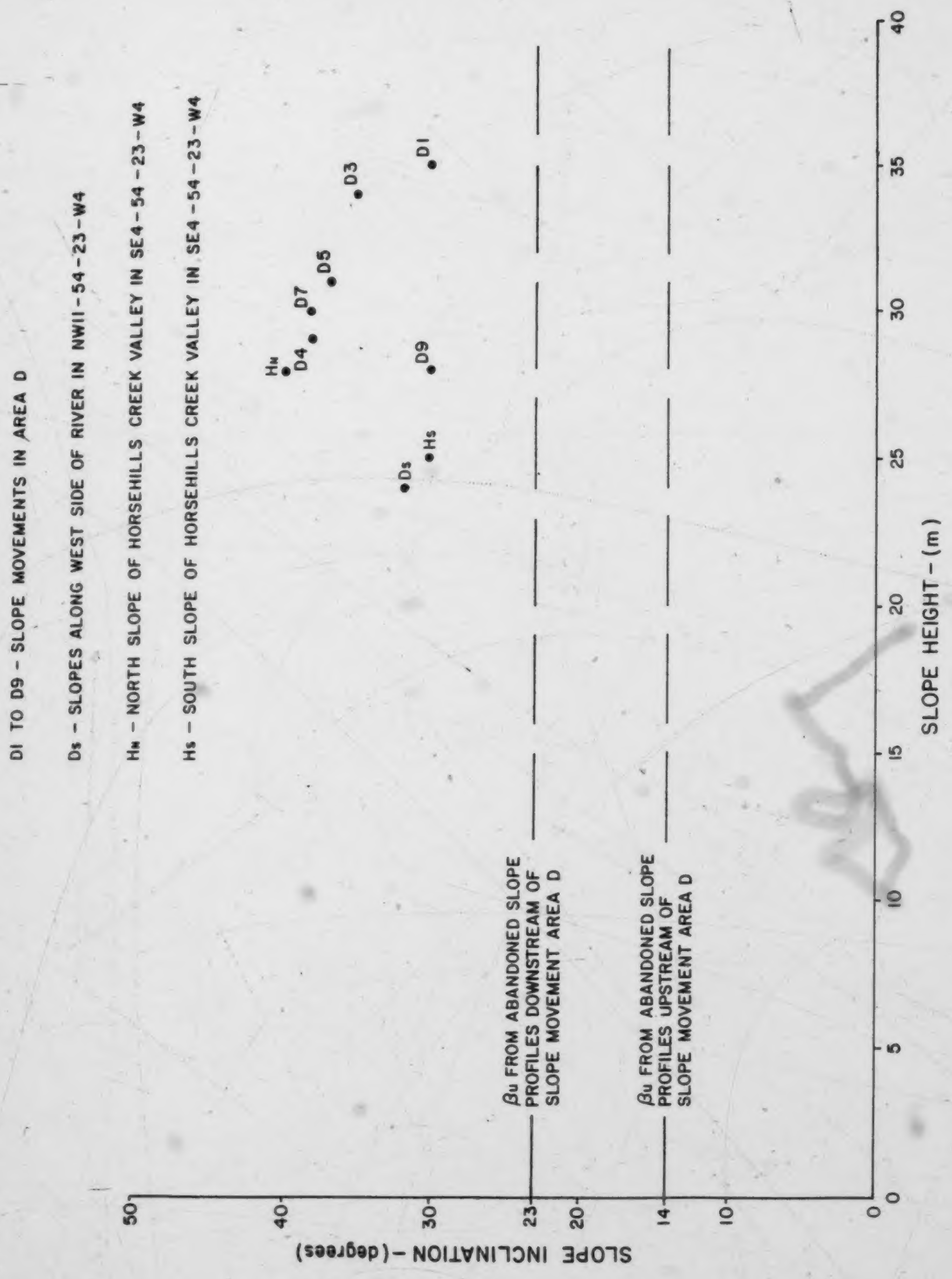
SLOPE INCLINATION VS. HEIGHT FOR SLOPE MOVEMENT AREA A - STRATIGRAPHIC CATEGORY I

SCALE AS SHOWN	SHEET 1 OF 1
DATE JUNE 1986	FIGURE 96

MICROFILM DATE

DRAWING No

FILE No



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NORTH SASKATCHEWAN RIVER SLOPE STUDY

SLOPE INCLINATION VS. HEIGHT FOR SLOPE MOVEMENT AREA D - STRATIGRAPHIC CATEGORY I

SUBMITTED	DESIGNED	SCALE AS SHOWN	SHEET 1 OF 1
DATE	CHECKED	DATE JUNE 1986	FIGURE 97
APPROVED	DRAWN		
DATE	TRACED		

MICROFILM DATE

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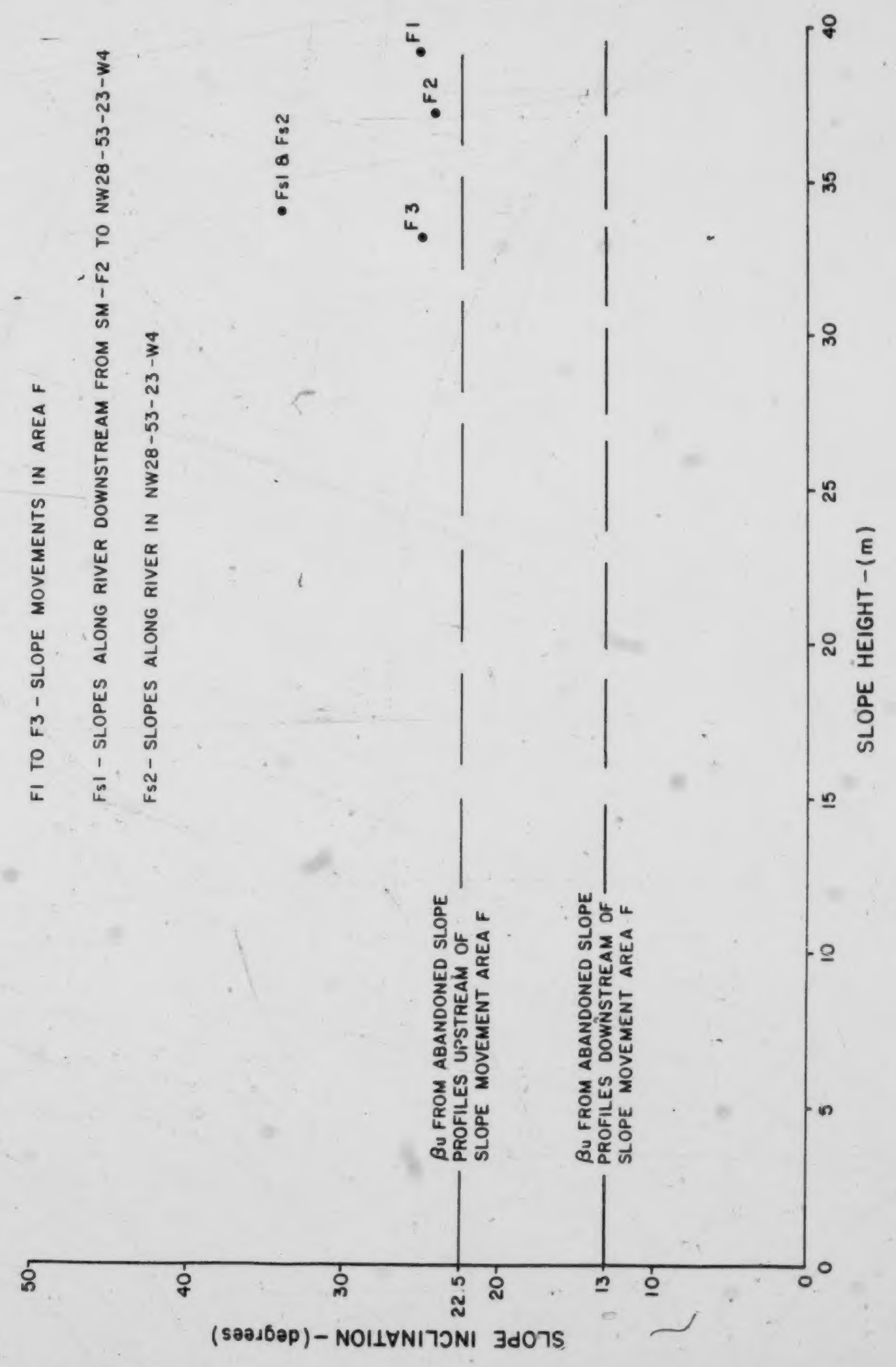

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NORTH SASKATCHEWAN RIVER SLOPE STUDY

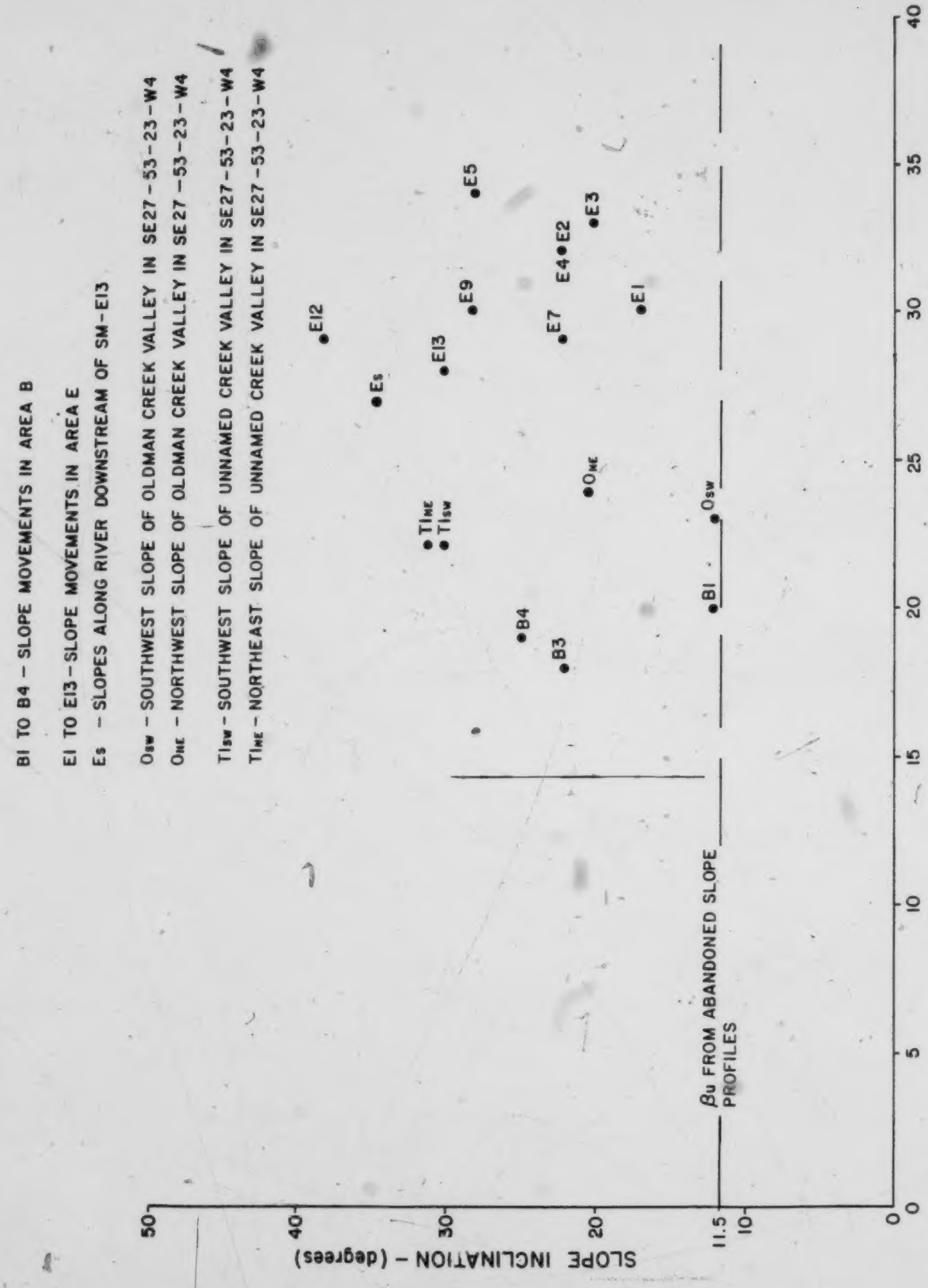
SLOPE INCLINATION VS. HEIGHT FOR SLOPE MOVEMENT AREA F - STRATIGRAPHIC CATEGORY I

SCALE AS SHOWN	SHEET 1 OF 1
DATE JUNE 1986	FIGURE 98

MICROFILM DATE

DRAWING No.

FILE No.



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APPROVED	DRAWN
DATE	TRACED

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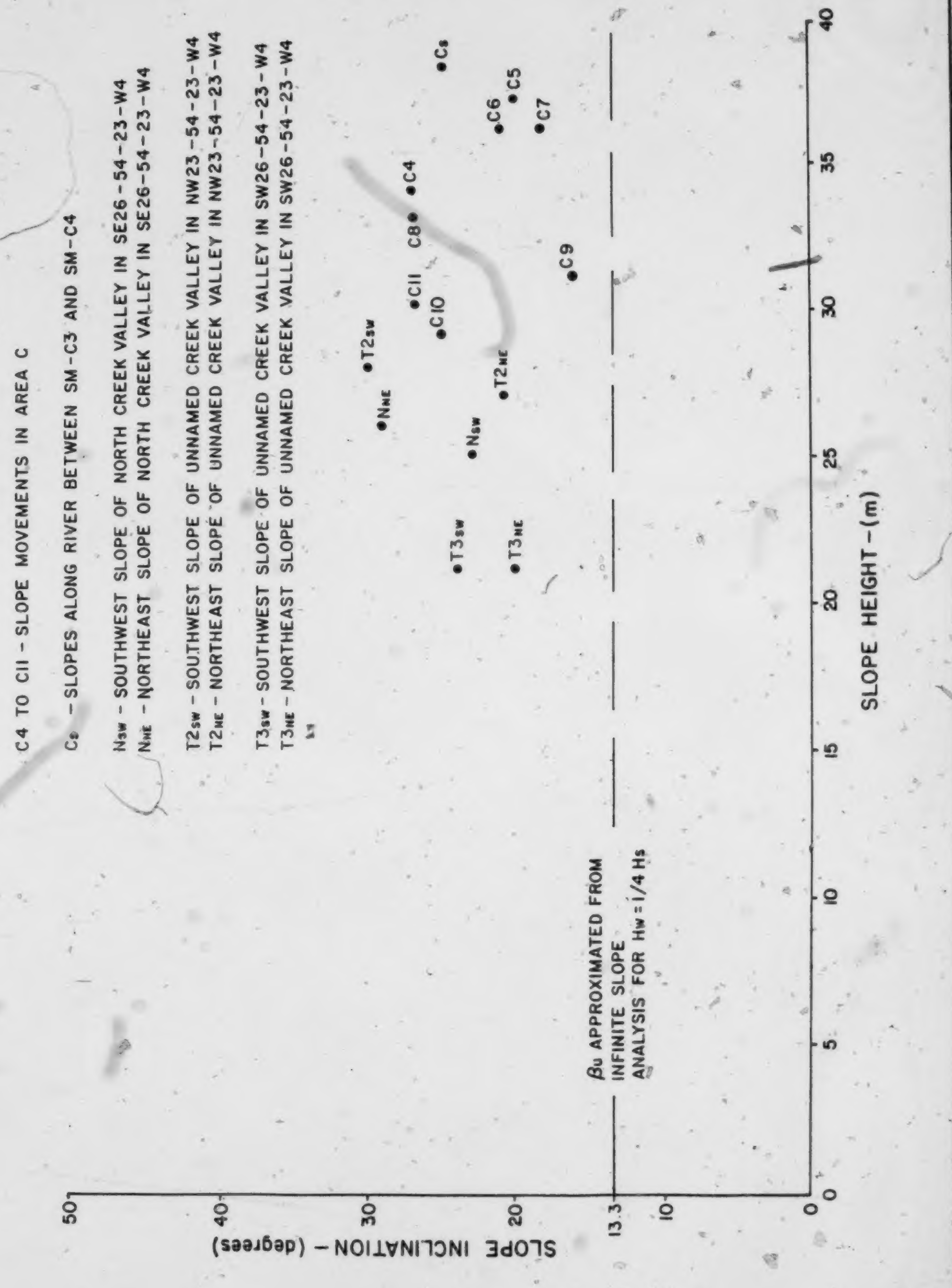
NORTH SASKATCHEWAN RIVER SLOPE STUDY

SLOPE INCLINATION VS. HEIGHT FOR SLOPE MOVEMENT AREAS B AND E – STRATIGRAPHIC CATEGORY 2

SCALE AS SHOWN	SHEET 1 OF 1
DATE JUNE 1986	FIGURE 99

DRAWING No.

MICROFILM DATE



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SUBMITTED	DESIGNED
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APPROVED	DRAWN
DATE	TRACED

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SLOPE INCLINATION VS. HEIGHT FOR SLOPE MOVEMENT AREA C - STRATIGRAPHIC CATEGORY 3

SCALE	AS SHOWN	SHEET 1	OF 1
DATE	JUNE 1986	FIGURE	100

is the slope height; β_u is the ultimate angle of stability and; α is the inclination of the oversteepened slope (Figure 90). The results of this calculation for each Stratigraphic Category are listed in Tables 9 to 11.

The potential long term regression for flow movements initiated by seepage and gully erosion are exceptions to the ultimate angle of stability theory as the mechanics of these movements are hydraulically governed. Mackay and Thomson (1980) have noted that flow movements act independently of slope height but depend on seepage pressures. Even if the slope becomes abandoned the seepage and erosion processes will continue to initiate flow movements as long as there is a water supply and uncontrolled drainage down the slope. For these movements the amount of valley crest regression is estimated from approximate measurements on airphotos dating back to 1924 (Tables 3 and 4). The amount of regression expected after 50 years with a continuation of existing seepage and erosion conditions is given in Tables 9 to 11.

5.2.2 Lateral River and Creek Erosion

The oversteepened slopes in Slope Movement Areas A to F are being eroded at their toe by the river. As indicated by Mollard (1981) lateral erosion should be considered in predicting the amount of valley crest regression. However, limited information is available on lateral erosion rates for the North Saskatchewan River through the City of Edmonton and nothing is available for the study area. To determine an accurate rate of net lateral river erosion requires a comparison of

TABLE 9 - SET-BACK GUIDELINES - STRATIGRAPHIC CATEGORY 1

LOCATION	DESCRIPTION/ SLOPE MOVEMENT	ULTIMATE ANGLE OF STABILITY β_u-(degrees)	INCLINATION OF OVERSTEEPENED SLOPES α-(degrees)	POTENTIAL LONG TERM REGRESSION R - (m)	NET LATERAL RIVER EROSION E_R - (m)	SET-BACK GUIDELINE SG - (m)	REMARKS
SLOPE MOVEMENT AREA A:							
River Lots 17&19-Ft.Saskatchewan	Abandoned valley slopes upstream of Slope Movement Area A	23.5	---	10	---	20	β_u applied to slopes in the upstream half of Area A
River Lot 17-Ft.Saskatchewan	SM-A1	23.5	30	13	15	30	Existing property line set-back of 30 to 40 m
River Lots 15&17-Ft.Saskatchewan	A_S1-Slopes along river from SM-A1 to SM-A2	23.5	45	30	15	45	Existing property line set-back of 30 to 40 m
River Lot 15-Ft.Saskatchewan	SM-A2	23.5	45	30	15	45	Existing property line set-back of 30 to 40 m
Northeast of Highway 15-~~Ft.Saskatchewan~~	Abandoned valley slopes downstream of Slope Movement Area A	16.5	---	10	---	20	β_u applied to slopes in the downstream half of Area A
River Lot 15-Ft.Saskatchewan	A_S2-Slopes along river between SM-A3 and SM-A4	16.5	38	46	15	60	Existing property line set-back of 30 to 40 m.
River Lot 15-Ft.Saskatchewan	SM-A4	16.5	34	44	15	60	Existing property line set-back of 30 to 40 m

TABLE 9 - SET-BACK GUIDELINES - STRATIGRAPHIC CATEGORY 1 (Cont'd)

LOCATION	DESCRIPTION/ SLOPE MOVEMENT	ULTIMATE ANGLE OF STABILITY β_u - (degrees)	INCLINATION OF OVERSTEEPENED SLOPES α -(degrees)	POTENTIAL LONG TERM REGRESSION R - (m)	NET LATERAL RIVER EROSION E_R - (m)	SET-BACK GUIDELINE SG - (m)	REMARKS
SLOPE MOVEMENT AREA D:							
SW33-53-23-W4	Abandoned valley slopes upstream of Slope Movement Area D	14	---	10	---	20	β_u applied to slopes in the upstream half of Area D, and along the Horsehills Creek valley
SE4-54-23-W4	SM-D1	14	30	80	15	95	
SE4-54-23-W4	SM-D3	14	35	88	15	105	
SE4-54-23-W4	SM-D4	14	38	79	15	95	
SE4 to NE4-54-23-W4	SM-D5	14	37	83	15	100	
HORSEHILLS CREEK VALLEY SLOPES:							
SE4-54-23-W4	H_S-South slope of creek valley	14	31	59	---	60	
SE4-54-23-W4	H_N-North slope of creek valley	14	40	79	---	80	
NE4-54-23-W4	SM-D6	---	---	23	15	40	Flow movement initiated by gully erosion R=50 (rate of regression)

TABLE 9 - SET-BACK GUIDELINES - STRATIGRAPHIC CATEGORY 1 (Cont'd)

LOCATION	DESCRIPTION/ SLOPE MOVEMENT	ULTIMATE ANGLE OF STABILITY β_u-(degrees)	INCLINATION OF OVERSTEEPENED SLOPES α-(degrees)	POTENTIAL LONG TERM REGRESSION R - (m)	NET LATERAL RIVER EROSION E_R - (m)	SET-BACK GUIDELINE SG - (m)	REMARKS
SLOPE MOVEMENT AREA D (cont'd):							
SE10-54-23-W4	Abandoned valley slopes downstream of Slope Movement Area D	23	---	10	---	20	β_u applied to slopes in the downstream half of Area D, and along river in NW11-54-23-W4 (D_S)
NE4 to SW3-54-23-W4	SM-D7	23	38	53	15	50	
NE3-54-23-W4	SM-D8	23	---	3	15	20	Flow movement initiated by seepage R=50 (rate of regression)
NE3-54-23-W4	SM-D9	23	30	17	15	30	
NW11-54-23-W4	D_S-Slopes along river downstream of Slope Movement Area D	23	31	17	15	40	Flow movement initiated by gully erosion R=50 (rate of regression)
SLOPE MOVEMENT AREA F:							
SE19 to NE19-53-23-W4	Abandoned valley slopes upstream of Slope Movement Area F	22.5	---	10	---	20	β_u applied to slopes in the upstream half of Area F
NE19 to SW29-53-23-W4	SM-F1	22.5	25	11	15	25	Existing set-back of 20 to 30 m from valley crest to edge of road

TABLE 9 - SET-BACK GUIDELINES - STRATIGRAPHIC CATEGORY 1 (Cont'd)

LOCATION	DESCRIPTION/ SLOPE MOVEMENT	ULTIMATE ANGLE OF STABILITY β_u-(degrees)	INCLINATION OF OVERSTEEPENED SLOPES α-(degrees)	POTENTIAL LONG TERM REGRESSION R - (m)	NET LATERAL RIVER EROSION E_R - (m)	SET-BACK GUIDELINE SG - (m)	REMARKS
SLOPE MOVEMENT AREA F (cont'd):							
NW29-53-23-W4	SM-F2	22.5	25	11	15	25	
NE29-53-23-W4	F_S1-Slopes along river in NE29-53-23-W4	22.5	34	32	15	50	
NW28-53-23-W4	Abandoned valley slopes downstream of Slope Movement Area F	13	---	10	---	20	β_u applied to slopes in in downstream half of Area F
NW28-53-23-W4	F_S2-Slopes along river in NW28-53-23-W4	13	34	97	15	110	
NW28-53-23-W4	SM-F3	13	25	72	15	85	

TABLE 10 - SET-BACK GUIDELINES - STRATIGRAPHIC CATEGORY 2

LOCATION	DESCRIPTION/ SLOPE MOVEMENT	ULTIMATE ANGLE OF STABILITY β_u-(degrees)	INCLINATION OF OVERSTEEPENED SLOPES α -(degrees)	POTENTIAL LONG TERM REGRESSION R - (m)	NET LATERAL RIVER EROSION E_R - (m)	SET-BACK GUIDELINE SG - (m)	REMARKS
SLOPE MOVEMENT AREAS B AND E:							
River Lots 14&22-Ft.Saskatchewan	Abandoned valley slopes upstream of Slope Movement Area B	11.5	---	10	---	20	β_u applied to slopes in Areas B and E, and along the Oldman Creek valley, and Unnamed Creek valley T1
River Lot 8-Ft.Saskatchewan	Abandoned valley slopes downstream of Slope Movement Area B						
SW21 to NW22-53-23-W4	Abandoned valley slopes upstream of Slope Movement Area E						
N1/235-53-23-W4	Abandoned valley slopes downstream of Slope Movement Area E						
River Lot 12-Ft. Saskatchewan	SM-B1	11.5	12	4	15	20	
River Lot 10-Ft.Saskatchewan	SM-B3	11.5	22	44	15	60	
River Lot 10-Ft. Saskatchewan	SM-B4	11.5	25	53	15	70	
SW27-53-23-W4	SM-E1	11.5	17	49	15	65	
SE27-53-23-W4	SM-E3	11.5	20	72	15	90	
SE27-53-23-W4	SM-E4	11.5	22	78	15	95	
SE27-53-23-W4	SM-E5	11.5	28	103	15	90	

TABLE 10 - SET-BACK GUIDELINES - STRATIGRAPHIC CATEGORY 2 (Cont'd)

LOCATION	DESCRIPTION/ SLOPE MOVEMENT	ULTIMATE ANGLE OF STABILITY β_u-(degrees)	INCLINATION OF OVERSTEEPENED SLOPES α-(degrees)	POTENTIAL LONG TERM REGRESSION R - (m)	NET LATERAL RIVER EROSION E_R - (m)	SET-BACK GUIDELINE SG - (m)	REMARKS
NE27-53-23-W4	SM-E7	11.5	22	71	15	85	
NE27-53-23-W4	SM-E9	11.5	28	74	15	90	
SE34-53-23-W4	SM-E13	11.5	30	90	15	105	
SE34-53-23-W4	E_S1-Slopes along river downstream of SM-E13	11.5	35	94	15	110	
OLDMAN CREEK VALLEY SLOPES:							
SW26-53-23-W4	O_{SW}-Southwest slope of creek valley	11.5	12	5	---	20	Minimum set-back applied
SW26-53-23-W4	O_{NE}-Northeast slope of creek valley	11.5	21	56	---	55	
UNNAMED CREEK VALLEY (T1):							
SE27-53-23-W4	$T1_{SW}$-Southwest slope of creek valley	11.5	31	72	---	70	
SE27-53-23-W4	$T1_{NE}$-Northeast slope of creek valley	11.5	32	73	---	75	

TABLE 11 - SET-BACK GUIDELINES - STRATIGRAPHIC CATEGORY 3

LOCATION	DESCRIPTION/ SLOPE MOVEMENT	ULTIMATE ANGLE OF STABILITY β_u-(degrees)	INCLINATION OF OVERSTEEPENED SLOPES α-(degrees)	POTENTIAL LONG TERM REGRESSION R - (m)	NET LATERAL RIVER EROSION E_R - (m)	SET-BACK GUIDELINE SG - (m)	REMARKS
SLOPE MOVEMENT AREA C:							
NH14-54-23-H4	Abandoned valley slopes upstream of Slope Movement [illegible] C	---	---	10	---	20	
NH14 to SH23-54-23-H4	SH-C1	---	27.5	10	15	25	Flow movement initiated by seepage R-50 (rate of regression)
SH23-54-23-H4	SH-C3	---	20	38	15	55	Flow movement initiated by gully erosion and seepage R-50 (rate of regression)
SH23-54-23-H4	C_S-Slopes along river between SH-C3 and SH-C4	13.3	25	76	15	90	β_u approximated from design charts (Vallejo and Edil, 1979) and applied to slopes in Area C, and along the North Creek valley and Unnamed Creek valleys T1 and T2.
SH23-54-23-H4	SH-C4	13.3	27	79	15	95	
NE23-54-23-H4	SH-C5	13.3	20	55	15	70	
NE23-54-23-H4	SH-C6	13.3	21	56	15	60	
SE26-54-23-H4	SH-C7	13.3	18	42	15	60	
SE26-54-23-H4	SH-C8	13.3	27	75	15	90	
SE26-54-23-H4	SH-C9	13.3	26	69	15	85	

TABLE 11 - SET-BACK GUIDELINES - STRATIGRAPHIC CATEGORY 3 (Cont'd)

LOCATION	DESCRIPTION/ SLOPE MOVEMENT	ULTIMATE ANGLE OF STABILITY β_u-(degrees)	INCLINATION OF OVERSTEEPENED SLOPES α-(degrees)	POTENTIAL LONG TERM REGRESSION R - (m)	NET LATERAL RIVER EROSION E_R - (m)	SET-BACK GUIDELINE SG - (m)	REMARKS
SE26-54-23-W4	SW-C10	13.3	25	61	15	75	
SE26-54-23-W4	SW-C11	13.3	27	68	15	85	
SW24-54-23-W4 & River Lot 30-Ft.Saskatchewan	Abandoned valley slopes downstream of Slope Movement Area C	---	---	10	---	20	
NORTH CREEK VALLEY SLOPES:							
SE26-54-23-W4	Southwest slope of creek valley	13.3	23	47	---	50	
SE26-54-23-W4	Northeast slope of creek valley	13.3	29	63	---	65	
UNNAMED CREEK VALLEY (T2):							
SW26-54-23-W4	$T2_{SW}$-Southwest slope of creek valley	13.3	24	42	---	40	
SW26-54-23-W4	$T2_{NE}$-Northeast slope of creek valley	13.3	20	31	---	30	
UNNAMED CREEK VALLEY (T3):							
NW23-54-23-W4	$T3_{SW}$-Southwest slope of creek valley	13.3	30	70	---	70	
NW23-54-23-W4	$T3_{NE}$-Northeast slope of creek valley	13.3	21	44	---	45	

ortho-corrected airphotos at the same scale dating as far back as they are available. As this is beyond the scope of this study, a conservative rate of erosion determined by a method similar to that used by Thomson and Townsend (1979) is applied to the study area. This involves measuring the distance to the river's edge from selected points, along lines common to a series of old survey plans and airphotos ranging in dates from 1883 to 1982. These measurements and a list of the survey plans and airphotos used is given in Table 12. The results range from 6 to 47 m/50 years, but commonly the rate of erosion is between 11.5 and 35 m/50 years. These rates are comparable to those determined by Thomson and Townsend (1979) of 7.5 to 16 m/50 years and 15 to 20 m/50 years for two locations in Edmonton and are slightly higher than an average of 5 to 10 m/50 years estimated by Fonstadt (personnel communication, 1985). The range of rates is probably due the variation in the amount of erosion which occurs within a meander, from one meander to another and with seasonal floods. As well, there are sources of error in the method of measurement such as airphoto distortion and accuracy of the measuring instrument. Considering the comparisons and the errors involved, a rate of 15 m/50 years is probably a conservative estimate for the North Saskatchewan River through the study area.

Examination of the older airphotos dating back to 1924 shows that the tributary creeks are eroding the toe of the slopes but at an insufficient rate to cause valley crest regression. The configuration of the valleys and position of the creeks have remained essentially unchanged for the past 60 years.

TABLE 12 - APPROXIMATION OF NET LATERAL RIVER EROSION

1. Slope Movement Area C

1.1 Measurement Line: - From mid point of boundary line between Sec. 15 and 22-54-23-W4 to toe of slope movement SM-C1

Airphotos			Survey Plans		Measurement
Date	Number	Scale	Date	Scale	(m)
			1917	1:31,680	825
1950	AS132	1:40,000			825
1972	AS1207	1:31,680			825
1982	AS2650	1:30,000			810

Net Lateral River Erosion ~ 11.5 m/50 Years

TABLE 12 - APPROXIMATION OF NET LATERAL RIVER EROSION (Cont'd)

2. Slope Movement Area D

2.1 Measurement Line - From mid point of boundary line between Sec.33-53-23-W4 and Sec.4-54-23-W4 to toe of slope movement SM-D1

Airphotos			Survey Plans		Measurement
Date	Number	Scale	Date	Scale	(m)
			1883	1:31,680	543
			1893	1:31,680	547
			1917	1:31,680	530
1950	AS133	1:40,000			510
1962	AS817	1:31,680			515
1982	AS2649	1:30,000			510

Net Lateral River Erosion ~ 12.5 m to 35 m/50 Years

2.2 Measurement Line - From north end of middle line of Sec.3-54-23-W4 to toe of slopes at downstream-end of Slope Movement Area D

Airphotos			Survey Plans		Measurement
Date	Number	Scale	Date	Scale	(m)
			1883	1:31,680	282
			1893	1:31,680	282
1924	CA72	1:15,840			253
1950	AS133	1:40,000			250
1962	AS817	1:31,680			249
1972	AS1207	1:31,680			257
1982	AS2649	1:30,000			260

Net Lateral River Erosion ~ 6 m to 47 m/50 Years

TABLE 12 - APPROXIMATION OF NET LATERAL RIVER EROSION (Cont'd)

3. Slope Movement Area E

3.1 Measurement Line - From southeast corner of Sec.27-53-23-W4 through toe of Slope Movement SM-E4 to middle of Sec.27

Airphotos			Survey Plans		Measurement
Date	Number	Scale	Date	Scale	(m)
			1916	1:31,680	829
1950	AS133	1:40,000			810
1982	AS2649	1:30,000			805

Net Lateral River Erosion ~18 m to 28 m/50 Years

3.2 Measurement Line - From mid point of boundary line between Sec.26 and 35-53-23-W4 to toe of slope movement SM-E10

Airphotos			Survey Plans		Measurement
Date	Number	Scale	Date	Scale	(m)
1950	AS133	1:40,000			800
1972	AS1207	1:31,680			797
1982	AS2649	1:30,000			800

Net Lateral River Erosion ~7 m/50 Years

TABLE 12 - APPROXIMATION OF NET LATERAL RIVER EROSION (Cont'd)

4. Slope Movement Area F

4.1 Measurement Line - From mid point of boundary line between Sec.20 and 29-53-23-W4 through toe or slope movement SM-F1 to northwest corner of Sec.30-53-23-W4

Airphotos			Survey Plans		Measurement
Date	Number	Scale	Date	Scale	(m)
			1883	1:31,680	950
			1917	1:31,680	945
1972	AS1207	1:31,680			910
1982	AS2649	1:30,000			920

Net Lateral River Erosion ~15 m to 31 m/50 Years

4.2 Measurement Line - From northwest corner of Sec.29-53-23-W4 along boundary line with Sec.28-53-23-W4 to toe of slopes in downstream end of Slope Movement Area F

Airphotos			Survey Plans		Measurement
Date	Number	Scale	Date	Scale	(m)
			1883	1:31,680	644
			1895	1:31.680	644
			1955	1:31,680	627
1950	AS133	1:40,000			625
1982	AS2649	1:30,000			615

Net Lateral River Erosion ~16.5 m to 23 m/50 Years

5.2.3 Effect of Urban Development

A significant effect of urban development is the potential rise in the groundwater table (Hamilton and Tao, 1977). This results in an increase of the groundwater pressure conditions and a decrease in the stability of the slopes. Potential sources of water include leaky storm sewers, irrigation systems, water reservoirs (swimming pools and dugouts) and weeping tile fields (R.M. Hardy & Associates Ltd., 1974, 1975a, 1975b; EBA Engineering Consultants Ltd., 1973; Mackay and Thomson, 1980; Ruban and Thomson, 1983). Infiltration of water from these sources can also result in the formation of perched water tables which may daylight on the slope as seepage and initiate flow movements. This effect is clearly illustrated in the study area as most of the flow movements are associated with seepage below existing homesteads and farmsteads. As well, the uncontrolled drainage of water down the slope results in the initiation of gully erosion and flow movements. The worst case of this in the study area is SM-C3 where a gully erosion in slopes comprised primarily of bedrock has caused up to 45 m of valley crest regression in the past 60 years.

Site specific development can impose changes to the load conditions of a slope (Townsend and Thomson, 1980; Thomson and Tiedemann, 1982). Excessive dumping of fill or debris over the valley crest or excavations near the toe create unstable load conditions. In the study area, fill and concrete blocks occur in the toe of slope movement SM-A4 while several old cars fill the gully of SM-D6 (Figures 24 and 63). It is probable that a lack of vegetation in the crown area makes these slopes readily accessible dump sites.

5.3 North Saskatchewan River Valley Set-Back Guidelines

5.3.1 Abandoned Slopes

As the abandoned valley slopes are considered to be at or near their ultimate angle of stability, their long term regression should be negligible. However, future urban development may increase the existing groundwater pressure conditions or alter the loading conditions and initiate movements. To account for this an empirical set-back is estimated from the amount of valley crest regression which has resulted from active slope movements bordering the river. Excluding flow movements the maximum regression of the valley crest over the past 60 years is 15 m for slope movements SM-C6, SM-C7 and SM-E1 (Table 4). Hence, a minimum set-back of 20 m is applied to the abandoned valley slopes to compensate for the potential of comparable movements occurring and to provide an additional 5 m to maintain access to the slopes in case remedial work is required (Tables 9 to 11).

5.3.2 Oversteepened Slopes

5.3.2.1 Stratigraphic Category 1

Slope Movement Areas A, D and F are included in Stratigraphic Category 1 as their oversteepened slopes are comprised of overburden soils. From river level their simplified stratigraphy consists of 13.5 m of sand and gravel overlain by 13 m of clay till which is overlain by 3.5

m of silty clay extending to the upland surface (Table 8). The groundwater table is taken as being at the bottom of the slopes.

The inclination of the abandoned slopes adjacent to these Slope Movement Areas vary between localities (Figure 91). For example, the abandoned slopes upstream of Slope Movement Area A have an average inclination of 23.5 degrees while on the downstream side their average inclination is 16.5 degrees. This variation may be due to changes in groundwater pressure conditions as indicated by theoretical values of the ultimate angle of stability determined for different positions of the groundwater table. With the groundwater table at the bottom of slopes an ultimate angle of stability of 24.5 degrees is obtained from Infinite Slope Analysis (Table 8). As a guideline this value is similar to the inclination of the abandoned slopes upstream of Slope Movement Areas A and F and those downstream of Area D. In contrast, with the groundwater table at three quarters of the slope height and an average residual angle of 24.5 degrees the design charts by Vallejo and Edil (1979) give approximately 10 degrees for an ultimate angle of stability (Figure 94). In addition with the groundwater table at the upland surface a value of 13.5 degrees is obtained from Infinite Slope Analysis (Table 8). These last two values approximately coincide with the lower inclination of the abandoned slopes on the downstream side of Slope Movement Area A and on the upstream side of Area D. This suggests that these slopes may have higher groundwater tables than inferred from the Slope Movement Areas. A higher groundwater table may be related to a lack of vegetation on the abandoned slopes with the lower inclinations. In densely vegetated slopes the groundwater table can be drawn down by absorption through the root system and high rates of evaportranspiration.

As the inclinations of the abandoned slopes are consistent at each locality, their average is considered to represent a site specific ultimate angle of stability only applicable to adjacent segments of the Slope Movement Areas (Figures 96 to 98). The average inclination of 23.5 degrees for the abandoned slopes upstream of Slope Movement Area A is the ultimate angle of stability applied to slope movements SM-A1, SM-A2 and intervening slopes along the river in the upstream half of Area A. Similarily, the abandoned slopes on the downstream side give an ultimate angle of stability of 16.5 degrees which is applied to SM-A4 and adjacent slopes in the downstream half of Area A. This results in potential long term regressions of 13 to 30 m for the slopes in the upstream half of Area A and 44 to 46 m for the slopes in the downstream half (Table 9). Using the same method for Slope Movement Area D gives potential long term regressions of 79 to 80 m for slopes in the upstream half of Area D up to and including SM-D5 and 17 to 33 m for the slopes in the downstream half excluding SM-D6 and SM-D8 which are flow movements. The slopes in the upstream half of Slope Movement Area F up to the western boundary of Sec. 28-53-23-W4 have potential long term regressions of 11 to 32 m while those in the downstream half have potential regressions of 72 to 97 m. Adding 15 m of net lateral river erosion gives the set-back guidelines, approximated to the nearest 5 m, listed in Table 9.

On the uplands behind Slope Movement Areas A and slope movement SM-F1 there are existing set-backs separating the valley crest from residential developments, which are similar to the guidelines established in this study. Behind Slope Movement Area A the existing set-back to the property line of the Pineview Subdivision ranges from 30 to 40 m. This is comparable to the 30 to 60 m guideline established in this study. Behind slope movement SM-F1 the existing set-back is approximately 20 m to the edge of a roadway bordering the Clareview Subdivision. This is also comparable to 25 m set-back guideline established in this study.

The existing set-backs were originally based on reports by EBA Engineering Consultants Ltd. (1973) for the Pineview Subdivision and by R.M. Hardy & Associates Ltd. (1976) for the Clareview Subdivision. In both cases a geotechnical slope stability investigation was performed.

5.3.2.2 Stratigraphic Category 2

The oversteepened slopes within Slope Movement Areas B and E fall within Stratigraphic Category 2 as they are comprised of overburden soils and bedrock strata with the overburden-bedrock contract in the lower half of the slopes. From river level their simplified stratigraphy begins with 11.5 m of interbedded clay shale and bentonitic shale (Table 8). Sandstone layers are also interbedded with the shale but they primarily occur below river level. These strata are overlain by 5 m of sand and gravel which in turn is overlain by 6 m of clay till and 4.5 m of clayey to silty sand extending to the upland surface. A conservative estimate of the position of the groundwater table is approximately half the slope height.

The inclinations for the abandoned valley slopes on the upstream and downstream sides of Slope Movement Areas B and F group around an average of 11.5 degrees regardless of slope height (Figure 92). Theoretical values for an ultimate angle of stability are comparable to this average inclination. The ultimate angle of stability from Infinite Slope Analysis with the groundwater table at half the slope height is approximately 11.7 degrees (Table 8). Extrapolation from the design chart data of Vallejo and Edil (1979) for an average residual angle of 18.1 degrees gives an ultimate angle of stability of approximately 10 degrees (Figure 94).

Using the average abandoned slope inclination of 11.5 degrees as the ultimate angle of stability results in potential long term regressions of 15 to 53 m for Slope Movement Area B and 49 to 94 m for Slope Movement Area E, excluding the flow movements (Table 10; Figure 99). Adding 15 m of net lateral river erosion to the potential long term regression gives the set-back guidelines, approximated to the nearest 5 m, also listed in Table 10.

5.3.2.3 Stratigraphic Category 3

Slopes within Stratigraphic Category 3 which are comprised primarily of bedrock strata with the overburden-bedrock contact in the upper half of the slope, occur in Slope Movement Area C. From river level their simplified stratigraphy consists of 30 m of interbedded clayey to bentonitic shale and sandstone, overlain by 4.5 m of clay till. The till is overlain by 2.5 m of silty clay which extends to the upland surface (Table 8). The groundwater table is taken as being at approximately a quarter of the slope height.

The abandoned valley slopes of Stratigraphic Category 3 have inclinations which average 20.5 degrees (Figure 93). As an ultimate angle of stability this value appears to be high in comparison to an average residual angle of 18.7 degrees for the bedrock strata and soils comprising the slope (Table 8). From Infinite Slope Analysis, theoretical values for the ultimate angle of stability range from approximately 11.3 degrees with the groundwater table at three quarters of the slope height, to 18.7 degrees with the groundwater table at the bottom of the slope. Extrapolation from the design chart data of Vallejo and Edil (1979) gives an ultimate angle of stability of approximately 13.3 degrees for the groundwater table at a quarter of the slope height (Figure 94).

Two factors which may account for the higher inclinations of these abandoned slopes are a lack of suitable profiles, and the slopes have not totally evolved to their ultimate angle of stability. The lack of profiles results from relatively small low level terraces occurring on either side of Slope Movement Area C and that these are the only slopes which fall into Stratigraphic Category 3. In addition, the abandoned slopes on both sides of Area C are densely treed which may have slowed their long term degradation by inhibiting weathering and erosion processes and the trend to zero of the cohesive component of strength.

The potential long term regression for the slopes in Area C are determined using the theoretical ultimate angle of stability of 13.3 degrees interpolated from the design charts for the groundwater table at a quarter of the slope height (Table 11; Figure 94). Excluding SM-C1 and SM-C3 which are flow movements, this results in potential long term regressions of 42 to 90 m. An additional 15 m of net lateral river erosion results in set-back guidelines approximated to the nearest 5 m as listed in Table 11.

5.3.2.4 Flow Movements

The set-back guidelines for the flow movements in the study area are listed in Tables 9 to 11 under the Slope Movement Area in which they occur. The guidelines are established by adding the estimated amount of valley crest regression to the amount of net lateral river erosion that is expected to occur over the next 50 years. For example, in slope movement SM-C3 the head of the gully has regressed up to 45 m over the past 60 years since 1924 (Table 4). A continuation of this rate of erosion will result in a further 38 m of regression over the next 50 years. With an additional 15 m of net lateral river erosion gives an approximated set-back guideline of 55 m for SM-C3.

5.4 Tributary Creek Valley Set-Back Guidelines

Set-back guidelines are established for the five major valleys and the three unnamed creek valleys in the study area as listed in Table 9 to 11. These guidelines are based on the potential long term regression of the oversteepened slopes along the creek valleys, determined by the same method used for the slopes bordering the river (Figure 90). The stratigraphy and groundwater pressure conditions of the slopes are inferred from the Slope Movement Area in which the mouth of the creek is located. With this inference the slopes are placed in a Stratigraphic Category. The potential long term regression is then determined using the appropriate ultimate angle of stability and the creek valley slope height and inclination data from Table 6. These data are also plotted on Figures 97, 99 and 100 along with the ultimate angle of stability applied. Since lateral creek erosion is considered to be negligible in the study area the resulting potential long term regressions equal the set-back guidelines. In addition as the slope height and inclination data is taken from profiles of the creek valleys near their mouths, the guidelines decrease 5 m for every 5 m decrease in valley depth upstream to the boundary of the study area.

5.4.1 Horsehills Creek

Horsehills Creek flows from the west through SE4-54-23-W4 and enters the North Saskatchewan River valley between SM-D4 and SM-D5 in Slope Movement Area D (Figures 105 and 106; Appendix 1). Near the mouth of the creek the valley slopes are 25 to 28 m high and have inclinations of 31 to 40 degrees (Table 6; Figure 85). Based on the stratigraphy exposed in

Slope Movement Area D and along the creek valley, these slopes are inferred to be comprised of overburden soils with the overburden-bedrock contact below creek level. Applying the ultimate angle of stability of 14 degrees from the abandoned river valley slopes on the upstream side of Slope Movement Area D, results in potential long term regressions and hence set-back guidelines of 60 to 80 m along the slopes near the mouth of the creek valley (Table 9; Figure 97). Further upstream these guidelines decrease to 35 to 50 m near the boundary of the study area in SE5-54-23-W4.

5.4.2 North Creek and Unnamed Creeks T2 and T3

North Creek enters the river valley from the northwest in SE26-54-23-W4 on the downstream side of SM-C11 in slope Movement Area C (Figures 110 and 111). Near the mouth of the creek, the valley slopes are 25 to 26 m high and have inclinations of 23 to 29 degrees (Table 6; Figure 86). The stratigraphy exposed in the downstream half of Slope Movement Area C suggests that these creek valley slopes are comprised primarily of bedrock with the overburden-bedrock contact in the upper half of the slopes. Applying the theoretical ultimate angle of stability of 13.3 degrees determined for Stratigraphic Category 3, results in set-back guidelines of 50 to 60 m along the slopes near the mouth of the creek (Table 111; Figure 100). Upstream to the boundary of the study area in NW26-54-23-W4 these guidelines decrease to 35 to 50 m.

Also inferred to be in Stratigraphic Category 3 are the slopes along two unnamed creek valleys, designated T2 and T3, which enter the river valley in SW26 and NW23-54-23-W4 respectively (Figures 100 and 110). Both the creek mouths are located in Slope Movement Area C, where the valley slopes of creek T2 are 27 to 28 m high and have inclinations of 21 to 30 degrees and the slopes of creek T3 are 21 m high and have inclinations of 20 to 24 degrees (Table 6). Combining this data with the ultimate angle of stability selected for Stratigraphic Category 3, results in set-back guidelines of 30 to 40 m for the slopes of creek T2 and 30 to 70 m for the slopes along creek T3 (Table 11).

5.4.3 Oldman Creek and Unnamed Creek T1

Oldman Creek enters the North Saskatchewan River valley in SE27-53-23-W4 between SM-E5 and SM-E6 in Slope Movement Area E (Figure 104). Upstream from its mouth only 300 m of the creek valley is encompassed by the the study area. Along this reach the creek valley slopes are 23 to 24 m high and have inclinations of 12 to 21 degrees (Table 6; Figure 87).

As inferred from Slope Movement Area E, these creek valley slopes are probably comprised of overburden soils and bedrock strata with the overburden-bedrock contact in the lower half of the slopes. Combining the ultimate angle of stability of 11.5 degrees for Stratigraphic Category 2 with the slope data results in set-back guidelines of 20 to 55 m along the Oldman Creek valley slopes (Table 10; Figure 99).

Approximately 0.8 km upstream along the river from the mouth of the Oldman Creek, an unnamed creek designated T1, enters the river valley in between SM-E2 and SM-E3 in Slope Movement Area E (Figure 104). Near the mouth of creek T1, the valley slopes are 22 m high and have inclination of 31 to 32 degrees (Table 6). These slopes are inferred to belong to Stratigraphic Category 2 which results in set-back guidelines of up to 75 m (Table 10; Figure 99).

5.4.4 Pointe-aux-Pins and Ross Creeks

The Pointe-aux-Pins and Ross Creek valleys were not investigated in detail by the writer due to the shallow depth of the valleys and lack of active slope movements (Table 6; Figures 107, 113 and 115). Examination of older airphotos dating back to 1924 show that these creek valley slopes have remained in a stable dormant condition for at least the past 60 years. With negligible creek erosion, future urban development is probably the only significant change that may initiate slope movements and regression of the valley crest. To account for this possibility the minimum set-back guideline of 20 m as established for the abandoned slopes along the river valley is considered suitable.

5.5 Summary

The set-back guidelines established for the North Saskatchewan River and tributary creek valley slopes in the study area are listed in Tables 9 to 11, and depicted on Figures 101 to 115 in Appendix 1. Excluding the flow movements, the guidelines for the oversteepened slopes in Slope Movement Areas A to F and along the creek valleys range from approximately 0.7 to 3.2 times the slope height. The minimum guideline of 20 m applied to the abandoned valley slopes is 0.5 to 1.5 times the slope height.

Of the results used to establish these guidelines Stratigraphic Category 2 shows agreement between an empirical ultimate angle of stability obtained from the inclinations of the abandoned valley slopes, and theoretical values determined from Infinite Slope Analyses and interpolation from the design chart data (Figure 92). These results show that in the long term the abandoned slopes have degraded to an inclination which approximates the theoretical ultimate angle of stability and is independent of slope height. In addition, the inclination data plotted on Figure 99 clearly shows that the oversteepened slopes have greater inclinations than the average of the abandoned slopes or ultimate angle of stability.

Similar relationships are suggested by the results for the abandoned slopes of Stratigraphic Category 1, but the data are not as consistent (Figure 91). In particular the oversteepened slopes always have greater inclinations than the average of the adjacent abandoned slopes. However, in this case the average inclination of the abandoned slopes can only be applied as a site specific ultimate angle of stability due to a possible variation in the position of the groundwater table between localities (Figures 96 to 98).

The results from Stratigraphic Categories 1 and 2 indicates that an estimate of the ultimate angle of stability can be obtained empirically from the long term degraded inclination of the abandoned valley slopes. Unless the oversteepened slopes are abandoned by the river or the movements become dormant for extended periods and allowed to degrade, their inclinations will always steeper than the empirical ultimate angle of stability. This difference provides a conservative set-back guideline based on the actual long term degradation of the abandoned slopes in the study area. Excluding flow movements the inclinations of the oversteepened slopes influences the magnitude of the resulting set-back guideline. Those with the lowest inclinations such as SM-B1, SM-E1 and SM-F1 have the least set-back guidelines while the steeply inclined movements occurring in Slope Movement Areas A' and D have considerably larger guidelines (Tables 9 to 11).

In contrast, the set-back guidelines established for the abandoned slopes and flow movements are based on short term conditions as the guidelines are derived from estimated amounts of valley crest regression over the past 60 years (Tables 4 and 9 to 11). These estimates are limited by the lack of airphoto coverage older than 1924 and the assumption that future regressions will not be greater than that which has occurred in this time period. This assumption relies on a continuation of existing slope loading and groundwater pressure conditions. The estimated rate of net lateral river erosion of 15 m/50 years and the potential effects of urban development could change these conditions in the long term. For these reasons, the set-back guidelines established for the abandoned slopes and the flow movements should be reassessed within the next 50 years.

CHAPTER 6

DISCUSSION AND CONCLUSIONS

6.1 Slope Movements Conditions

6.1.1 North Saskatchewan River Valley

The slope movements in the study area are dominated by three types. In order of predominance these are translational, compound rotational-translational and flow movements. The occurrence of the translational and combined rotational-translational movements appears to be directly related to slope stratigraphy and groundwater pressure conditions and initiated by lateral river erosion while flow movements are solely governed by seepage and run-off and the uncontrolled downslope drainage of this water.

Translational slides can be divided into shallow and deep-seated based on the depth of the rupture surface in the slope. The shallow slides are most common accounting for approximately 29 percent of the slope movements classified in the study area. This type occurs in Slope Movement Areas A, B and D with typical examples being SM-A2, SM-B1, SM-D3 to SM-D5, SM-D7 and SM-D9 (Table 4). Their movement involves the downslope sliding of blocks of overburden soils which have separated from the main scarp. Block separation may be initiated by a deterioration of shear strength along fractures and joints due to saturation and repeated freeze-thaw of infiltrated water, as described by Ruban and Thomson (1983) for block movements on the slopes along the Oldman River.

The rupture surface of these shallow slides in the study area occurs between the underside of the moving blocks and the slope surface. The amount of resulting valley crest regression is related to the size of the separated block which in turn depends on the position of fractures and joints in the crown area.

In Slope Movement Areas A and D there is a notable absence of deep-seated movements even though the unmoved slopes are inclined up to 45 degrees. This stable condition is attributed to the presence of Saskatchewan sand and gravel in the slopes and the occurrence of the bedrock and its weak planes below river level. The stabilizing effect of the Saskatchewan sand and gravel in the study has been previously recognized by EBA Engineering Consultants Ltd. (1973) and Thomson and Bruce (1978). This effect is a result of a high angle of shearing resistance of approximately 35 degrees and the underdrainage of the slope provided by the permeable sediments which serves to draw down the groundwater table. The occurrence of bedrock strata below river level decreases the potential for a rupture surface to develop along a weak plane such as a bentonite seam or in the bentonitic shales.

Deep-seated translational movements are less common than the shallow block slides, only accounting for 10 percent of the classified slope movements in the study area. This type of movement is confined to the upstream end of Slope Movement Area E and is represented by SM-E1, SM-E3 and SM-E4 (Table 4). These movements show the effect of weak planes in the bedrock strata occurring above river level combined with lateral river erosion, in creating unstable conditions. The detailed investigation by Thomson (1971) of SM-E1 (Lesueur Landslide) showed that the rupture surface under the movement developed along a horizontal weak plane near the bottom of a clay shale layer at 1 to 1.5 m above river level. Unloading of the toe by lateral river erosion was attributed as a significant factor for the occurrence of SM-E1.

Similar geomorphic features and the occurrence of displaced bedrock material in the toes of SM-E3 and SM-E4 leads to the conclusion that they also underwent the same translational movement as SM-E1. As well, river erosion is still active along the toe of these movements as indicated by the gradual removal of the displaced material which bulges into the river.

Compound rotational-translational movements account for 38 percent of the classified slope movements in the study area almost equalling the total number of translational movements (Table 4). The compound movements occur mainly in Slope Movement Areas C and F with typical examples being SM-C4 to SM-C9 and SM-F1 to SM-F3. In these movements, there appears to be three positions of the rupture surface as represented in SM-C4, SM-F1 and SM-C7. Slope movement SM-C4 has its rupture surface along the overburden-bedrock contact exposed at the top of a steep bedrock slope rising 20 to 25 m above river level. The rupture surface of SM-F1 is probably also along the overburden-bedrock contact but in this movement the contact is located approximately 2 m below river level. In contrast, the rupture surface of SM-C7 is suspected as being along a weak plane in the bedrock strata at 1 to 2 m below river level. In Area C intense lateral river erosion is occurring as shown by the secondary slides and falls at the toes of SM-C5 to SM-C9 while in Area F, SM-F1 to SM-F3 have been subjected to periodic erosion probably during higher river levels.

The significant role of lateral river erosion in initiating slope movements has been noted in several previous studies (Thomson, 1970, 1971; Thomson and Morgenstern, 1977; Thomson and Townsend, 1979; Thomson and Bruce, 1978; Mackay and Thomson, 1980; Thomson and Tiedemann, 1982; Ruban and Thomson, 1983). Lateral river erosion also appears to be a significant factor in aggravating or possibly initiating many of the slope movements in the study area. The continual or periodic removal of displaced material from the toe of the shallow translational slides may aggravate the downslope movement of the blocks by preventing a build-up of displaced material at the toe. In addition, by unloading the toe, river erosion may have been a significant factor in initiating the translational and compound rotational-translational movements which occurred along rupture surfaces near river level. Besides the undercut banks and secondary slides and falls which occur at the toes of most of the slope movements in the study area, further evidence is provided by the occurrence of the movements in groups where the main current of the river is flowing against the toe of the slopes. Slope Movement Areas C, D, E and F are located along the outside of meanders in the river (Figure

1; Appendix 1). Slope Movement Area A is located downstream of a gentle bend in the river while the downstream end of Area C and Slope Movement Area B are located opposite islands in the river.

Previous studies in other areas have noted a dramatic decrease in slope movement activity where a river valley follows or intersects a preglacial valley containing Saskatchewan sand and gravel deposits (Thomson and Morgenstern, 1977, 1979; Thomson and Bruce, 1978; Mackay and Thomson, 1980). As discussed previously the occurrence of Saskatchewan sand and gravel in the slopes of the study area also has a stabilizing effect. However. this effect appears to be undermined where Upper Cretaceous bedrock strata and associated weak planes underlie the sand and gravel in the lower half of the slopes.

The occurrence of the sand and gravel and bedrock strata in the slopes can be related to the position of the North Saskatchewan River with respect to the underlying preglacial Beverly Valley as depicted on the bedrock topography map by Carlson (1967). Through Slope Movement Areas A, D and F the river valley slopes are positioned towards the middle of the Beverly Valley. In these areas the preglacially eroded bedrock surface is approximately 2 to 4 m below river level and up to 20 m of sand and gravel overlies bedrock to form the lower half of the river valley slopes. As noted previously deep-seated movements are absent in Slope Movement Areas A and D and only three occur in the 3.5 km stretch of slopes in Area F.

Through Slope Movement Area E the river valley slopes are positioned against the southeast sideslope of the Beverly Valley, formed by approximately a 30 m rise in the bedrock surface towards the uplands. In the river valley slopes, bedrock extends 7 to 15 m above river level and is overlain by approximately 6 m of sand and gravel. Slope Movement Area E contains a series of movements seated in the bedrock strata at river level (SM-E1, SM-E3 and SM-E4) and along the overburden bedrock contact higher in the slopes (SM-E7 to SM-E9 and SM-E13). Similarly, further downstream in the study area through Slope Movement Area C, the river valley slopes are positioned against the northwest sideslope of the Beverly Valley formed by a 61 m rise in the bedrock surface towards the uplands. In Area C, bedrock comprises up to 32 m of the river valley slopes and is overlain by 7 m of glacially derived soils with an absence of Saskatchewan sand and gravel. In these slopes a series of movements occur seated in bedrock near river level (SM-C5, SM-C7 and SM-C9) and along the overburden bedrock contact higher in the slopes (SM-C4, SM-C6 and SM-C8).

Flows account for 23 percent of the classified slope movements in the study area (Table 4). Their occurrence is not predominant in any of the Slope Movement Areas except for SM-D6, they occur below homesteads or farmsteads and their initiation can generally be correlated with the construction of the houses and farm buildings.

The flow movements are associated with seepage discharging from permeable layers in the overburden soils such as sand lenses in the till and sandy glaciolacustrine sediments (SM-C1 and SM-D8) or, at the overburden-bedrock contact usually where Saskatchewan sand and gravel overlies bedrock (SM-E12). The flow movements which have resulted from gully erosion usually have seepage discharging from the flanks of the gully or on adjacent slopes (SM-C3 and SM-E6). It is evident that the movement is directly related to a continued supply of seepage or run-off water and the uncontrolled discharge of this water down the slope. Slope stratigraphy influences the formation of these movements through the creation of perched water tables in layers of lenses of sediments with a higher horizontal component of permeability than the surrounding soils or bedrock strata. For seepage to occur, these sediments have to daylight in the slope creating a hydraulic gradient within the layer or lens. With lateral river erosion at the toe the displaced material is continually removed aggravating the downslope movement of the saturated material.

With continued seepage and uncontrolled downslope drainage it is expected that most of the flows, in particular SM-C1 and SM-C3 will eventually encroach upon the houses and associated buildings located directly on the uplands. These movements could be stabilized through the installation of a drainage system in the slope to control seepage and downslope erosion. However, such remedial measures are likely to be expensive.

6.1.2 Tributary Creek Valleys

Along the creek valley slopes there is an absence of deep-seated movements which can be classed as active or inactive-young. There is a gap in slope movement activity between the active shallow translational slides and falls confined to undercut slopes on the outside of creek meanders and the larger inactive-mature slope movements with their main scarps forming the valley crests. McCalpin (1984) has inferred an age of 5,000 to 10,000 years old for inactive-mature slope movements (Table 2). This indicates that the older movements along the creek valleys probably occurred during late glacial and early postglacial times. The gradient of the creek valleys during their formation in this period would be governed by the level of the North Saskatchewan River. Thomson and Tiedemann (1979) have suggested that the river valley underwent a period of rapid vertical erosion in early postglacial times which downcut the valley to the low level terraces prior to 8,000 years old. It follows that the tributary creek valleys must have downcut at a similar rate to the same level in this period. The absence of deep-seated active or inactive-young slope movements along the creek valleys indicates that the rate of valley formation has decreased since this period of initial downcutting. The creek valleys are still in a quiescent period of vertical or lateral erosion as their configuration has remained essentially unchanged for at least the past 60 years.

The prominence of the inactive-mature slope movements on the generally south facing slopes of the creek valleys is due to a sparse vegetation cover. This may be in part due to longer hours of direct sunlight producing a drier microclimate in comparison to the densely treed north facing slopes.

6.2 Set Back Guidelines

The set-back guidelines established for the North Saskatchewan River and tributary creek valley slopes in the study area, as depicted on Figures 101 to 115, are measured back from an approximate valley crest line. The guidelines are intended for preliminary land use decisions and their application requires that the valley crest line be accurately surveyed. They should also be reassessed within 50 years with regard to changes in the existing slope conditions due. The 50 year limit represents the outer confidence level on the extrapolation of the estimated rates of lateral river erosion and valley crest regression associated with the flow movements.

Based on the ultimate angle of stability theory, the set-back guidelines established for the oversteepened slopes in the study area range from 0.7 to 3.2 times the valley depth. In comparison, previous studies in other urban areas which applied a "rule-of-thumb" set-back, based on the amount of valley crest regression measured from active slope movements, usually established guidelines of 1 to 2 times the valley depth (Mackay and Thomson, 1980; Ruban and Thomson, 1983). A disadvantage of this latter method is that the amount of measurable regression is limited by the availability of records and airphotos which are usually less than 100 years old. In applying the ultimate angle of stability concept the long term degradation of abandoned valley slopes over several thousand years is incorporated to provide a guideline of the potential regression of the actively moving oversteepened slopes which border the river and creeks.

The set-back guidelines established for the study area could be refined with at least 10 additional boreholes to determine accurately the stratigraphy and groundwater pressure conditions of the abandoned river and tributary creek valley slopes. Stratigraphic control is important due to the effect of the preglacial Beverly Valley in governing the stratigraphic and groundwater pressure conditions. The variability in stratigraphy from one side of the North Saskatchewan River valley to the other undermines confidence in inferring these conditions as shown by the results for Stratigraphic Categories 1 and 3 (Figures 91 and 93).

The detailed subsurface information obtained from the boreholes could also be used in computer aided slope stability analyses on typical cross-sections to determine a more soundly based ultimate angle of stability for each Stratigraphic Category. This would provide a better comparison for the empirical values obtained from the abandoned slope profiles.

Extrapolation of the design chart data of Vallejo and Edil (1979) from the summary plot compiled by Mollard (1981) provides a quick method for establishing potential, long term regression of oversteepened slopes based on the ultimate angle of stability concept. As there is a continual need to establish preliminary set-back guidelines along extensive reaches of river and creek valleys through expanding urban areas, additional charts and summary plots for the three basic positions of the groundwater table should be developed. For example, a set of charts could be developed particularly for the Edmonton area based on the predominant values of residual angles of shearing resistance and bulk unit weights of the soil and bedrock strata which commonly occur in the river and creek valley slopes.

The accurate, site specific determination of net lateral erosion would further refine the set-back guidelines. These data would also be useful to geotechnical, river and transportation engineering studies that involve the river valley slopes and floodplain.

6.2.1 Development Restrictions

Significant effects of future residential developments are liable to be the generation of seepage and the uncontrolled discharge of water down the slopes. These effects are clearly shown by the existing flow movements in the study area. To avoid this possibility the following initial restrictions should be employed with regard to residential developments:

1. The guidelines should be taken as property-line set-backs and the intervening land designated as environmental reserve. This provides a buffer between the slope and potential sources of water such as leakage from water mains, sewers, swimming pools and lawn watering. As well, this will deter the dumping of debris or clearing of vegetation down the slope by individual property owners and provide access if remedial slope work is required.

2. Water carrying services such as watermains and sewers which, in the design of the development, must be located between the valley crest and the set-back should be constructed to control potential leakage so that it will not influence the existing groundwater pressure conditions of the slopes. In addition, any outfall or drainage outlet to be located on the slopes should be designed to control the discharge of water and downslope drainage.

For major building structures such as apartments or industrial complexes, imposed changes to the slope loading and groundwater pressure conditions will vary depending on their site specific design. In the investigation and design stages for such structures a geotechnical slope stability investigation as outlined by Townsend and Thomson (1980) should be required to establish appropriate building set-backs. This investigation should be based on computer aided stability analyses using site specific stratigraphy and groundwater information obtained from geomorphological mapping and a borehole drilling program. The analyses should also incorporate any changes to the loading and groundwater pressure conditions that may result from the development. As well, any existing slope movement adjacent to the building site should be established.

In summary, the land encompassed by the set-back guidelines should be considered as a restricted development area. Development in this area that may impose changes to the slope loading or groundwater pressure conditions should require a geotechnical slope stability investigation which includes appropriate analyses using site specific stratigraphy and groundwater information to show that a lesser set-back is safe and acceptable.

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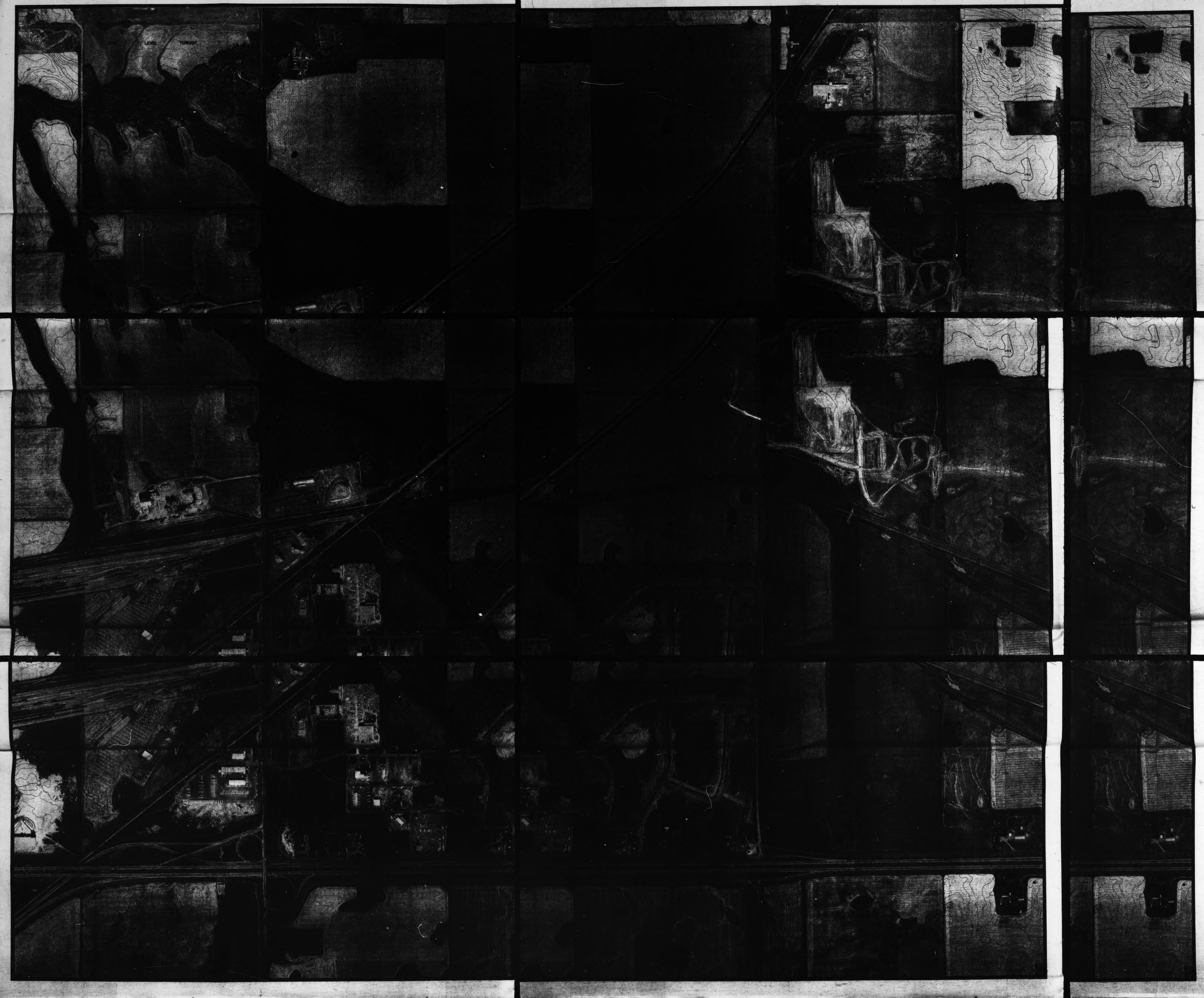
FORT SASKATCHEWAN
RESTRICTED DEVELOPMENT AREA
MAP

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS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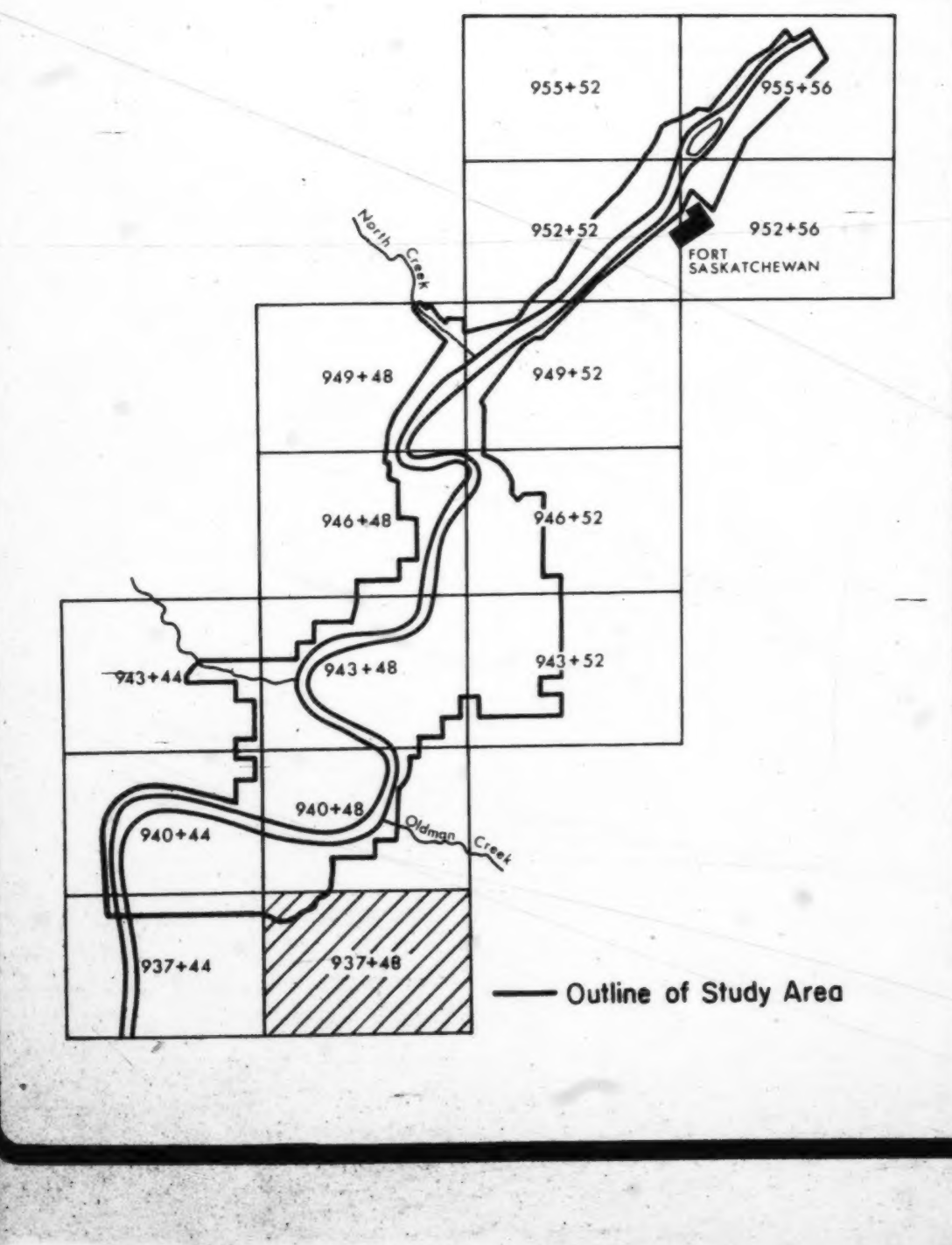
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FORT SASKATCHEWAN
North Creek
949+48
949+52
946+48
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943+44
943+48
943+52
940+44
940+48
Oldman Creek
937+44
937+48
Outline of Study Area

Scale 1:5000

metres
0 50 100 200 400 600
0 200 500 1000 1500 2000
feet
N

LEGEND

— - — SET-BACK GUIDELINE

—— APPROXIMATE VALLEY CREST LINE

⬭ ACTIVE AND INACTIVE-YOUNG SLOPE MOVEMENTS

⋯ INACTIVE-MATURE SLOPE MOVEMENTS

Cadastral Number: 937 + 48
53-23-W4

Figure 102

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Prepared by: ECOLOGICAL LAND SURVEYS LTD.

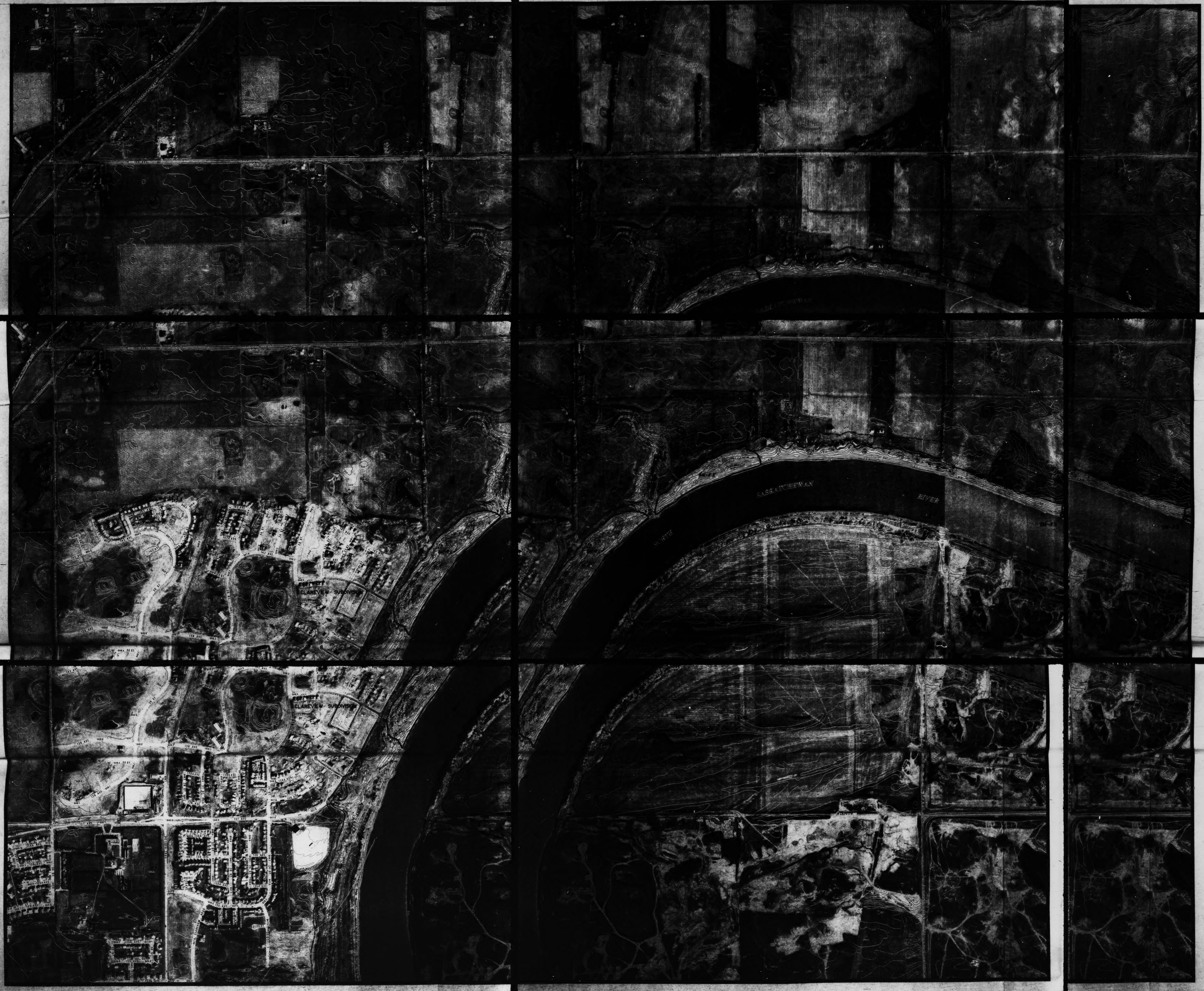
FORT SASKATCHEWAN
RESTRICTED DEVELOPMENT AREA
MAP

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS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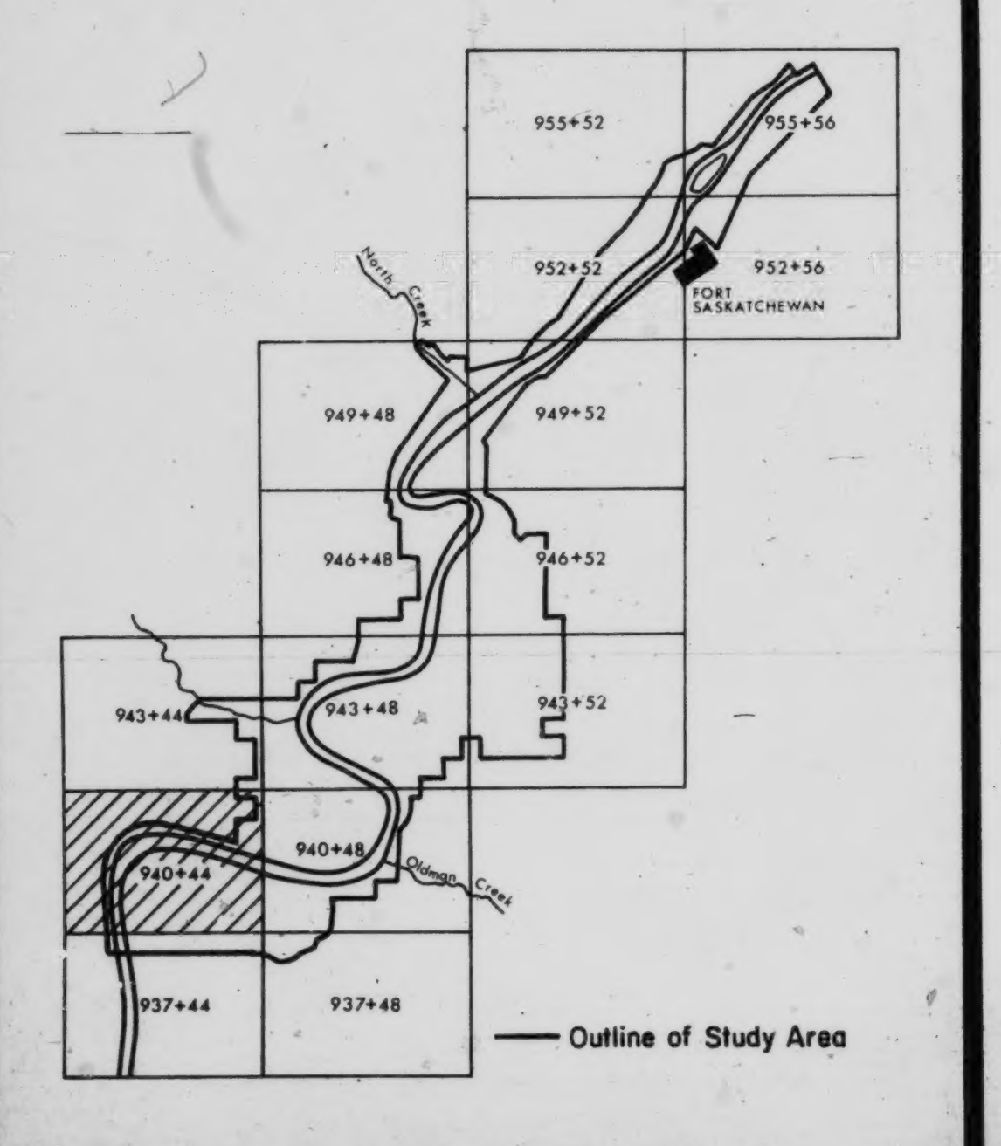
RIVER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FORT SASKATCHEWAN
North Creek
949+48
949+52
946+48
946+52
943+44
943+48
943+52
940+44
940+48
Oldman Creek
937+44
937+48
Outline of Study Area

Scale 1:5000

metres: 0, 50, 100, 200, 400, 600

feet: 0, 200, 500, 1000, 1500, 2000

N

LEGEND

— — —	SET-BACK GUIDELINE
———	APPROXIMATE VALLEY CREST LINE
⬭	ACTIVE AND INACTIVE-YOUNG SLOPE MOVEMENTS
⋯	INACTIVE-MATURE SLOPE MOVEMENTS

Cadastral Number: 940 + 44
53-23-W4

Figure 103

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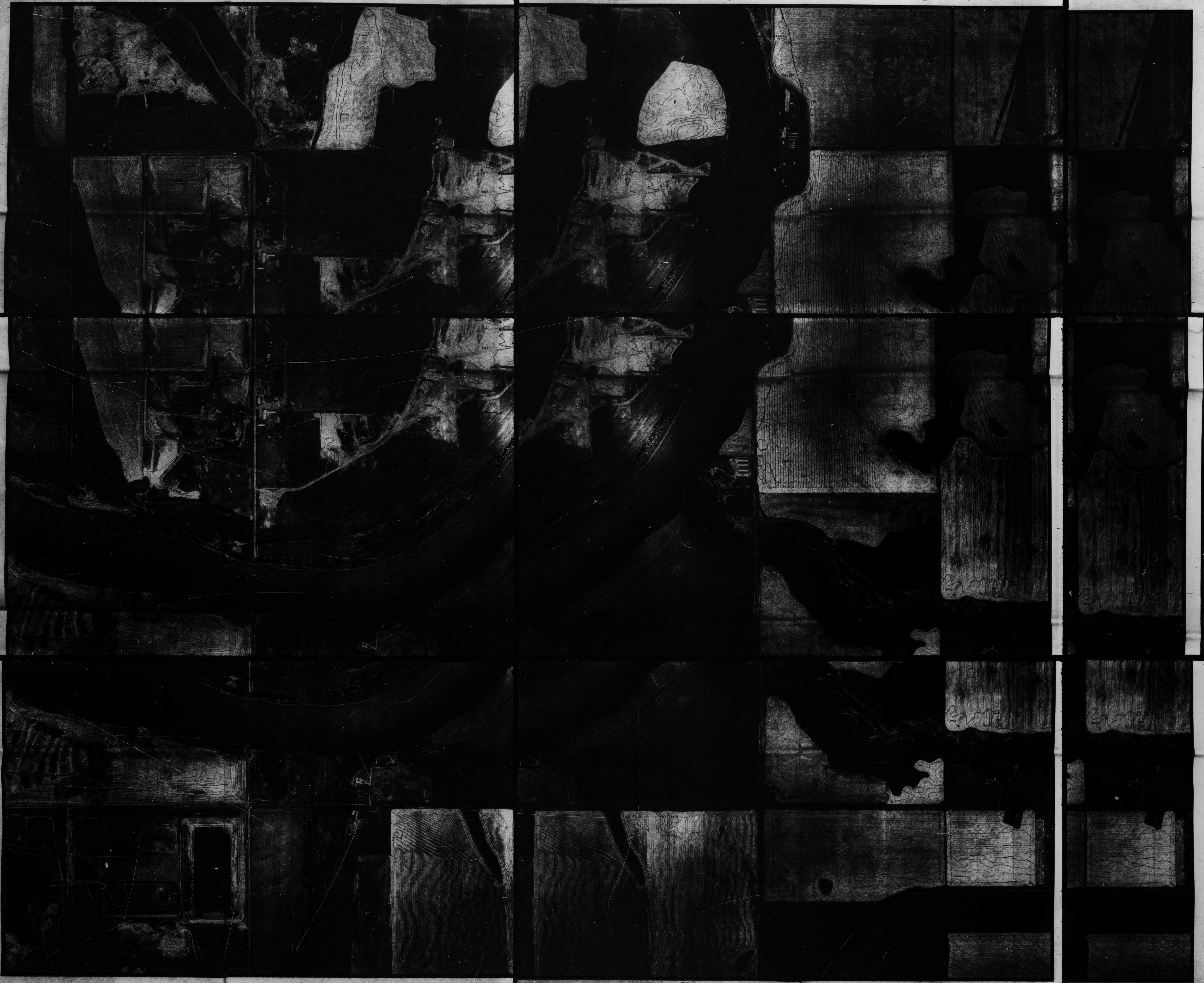
FORT SASKATCHEWAN
RESTRICTED DEVELOPMENT AREA
MAP

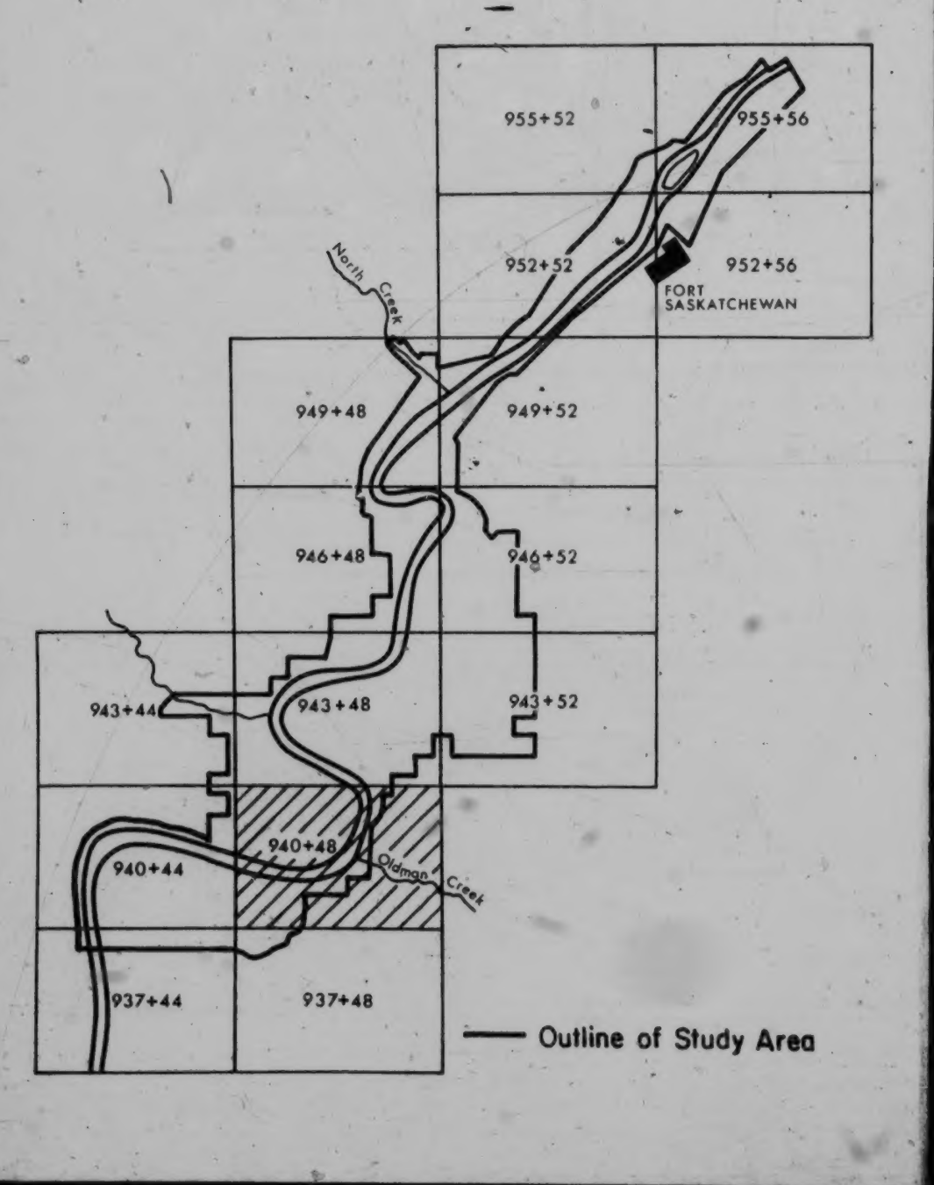
NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS

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North Creek
FORT SASKATCHEWAN
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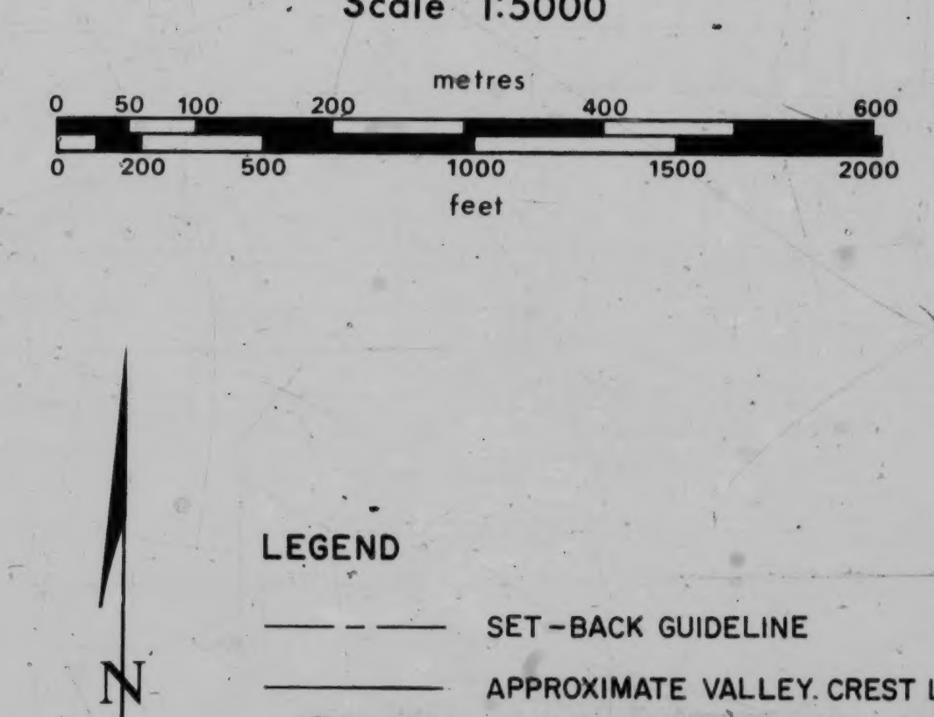
940+44
940+48
Oldman Creek
937+44
937+48
Outline of Study Area

Scale 1:5000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LEGEND

— — —	SET-BACK GUIDELINE
——	APPROXIMATE VALLEY CREST LINE
⬭	ACTIVE AND INACTIVE-YOUNG SLOPE MOVEMENTS
⋯	INACTIVE-MATURE SLOPE MOVEMENTS

Cadastral Number: 940+48
53-23-W4

Figure 104

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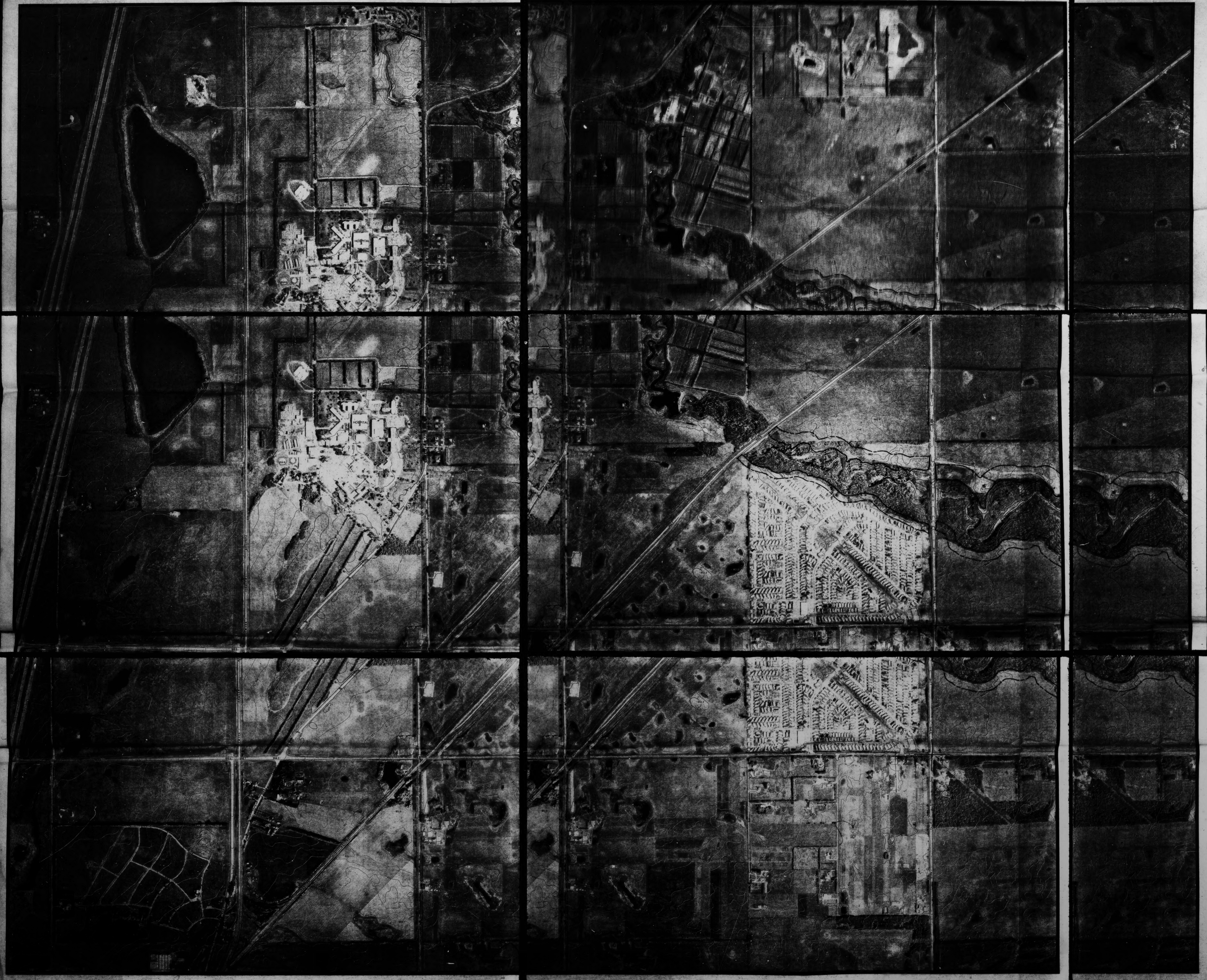
FORT SASKATCHEWAN
RESTRICTED DEVELOPMENT AREA
MAP

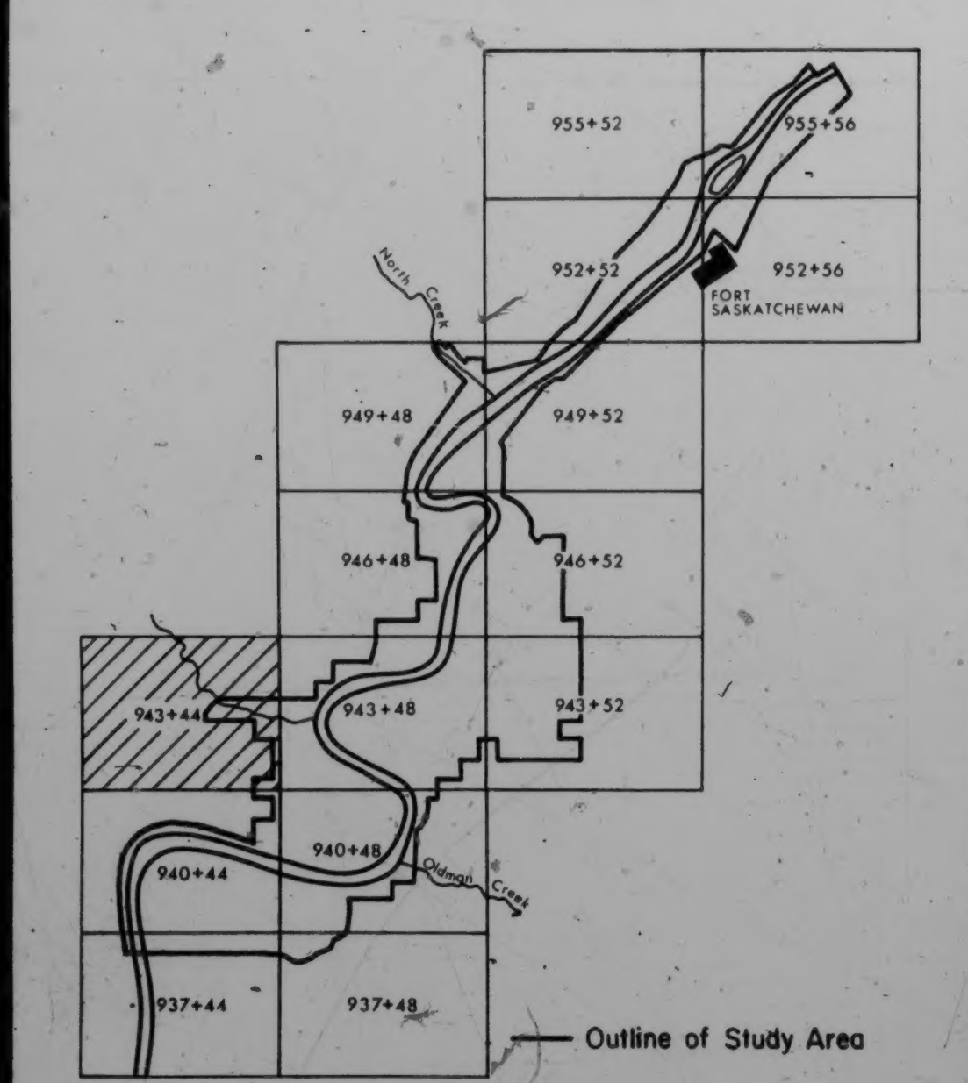
NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES AND SLOPE MOVEMENT LOCATIONS

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES AND SLOPE MOVEMENT LOCATIONS

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FORT SASKATCHEWAN
North Creek
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940+48
Oldman Creek
937+44
937+48
Outline of Study Area

Scale 1:5000

metres
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feet
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LEGEND

— – —	SET-BACK GUIDELINE
——	APPROXIMATE VALLEY CREST LINE
⬭	ACTIVE AND INACTIVE-YOUNG SLOPE MOVEMENTS
⋯	INACTIVE-MATURE SLOPE MOVEMENTS

Cadastral Number: 943+44
53 & 54-23-W4

Figure 105

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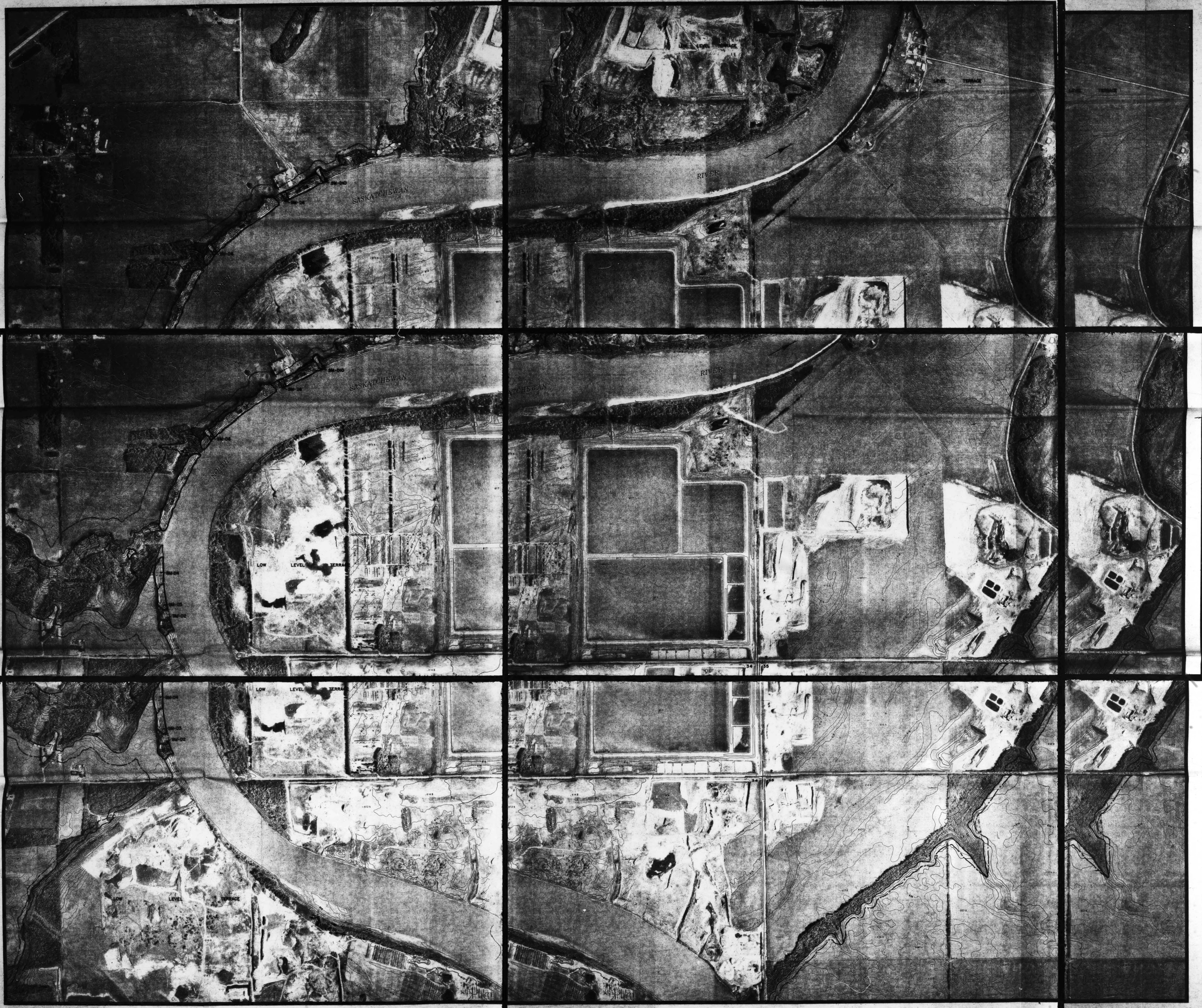
FORT SASKATCHEWAN
RESTRICTED DEVELOPMENT AREA
MAP

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS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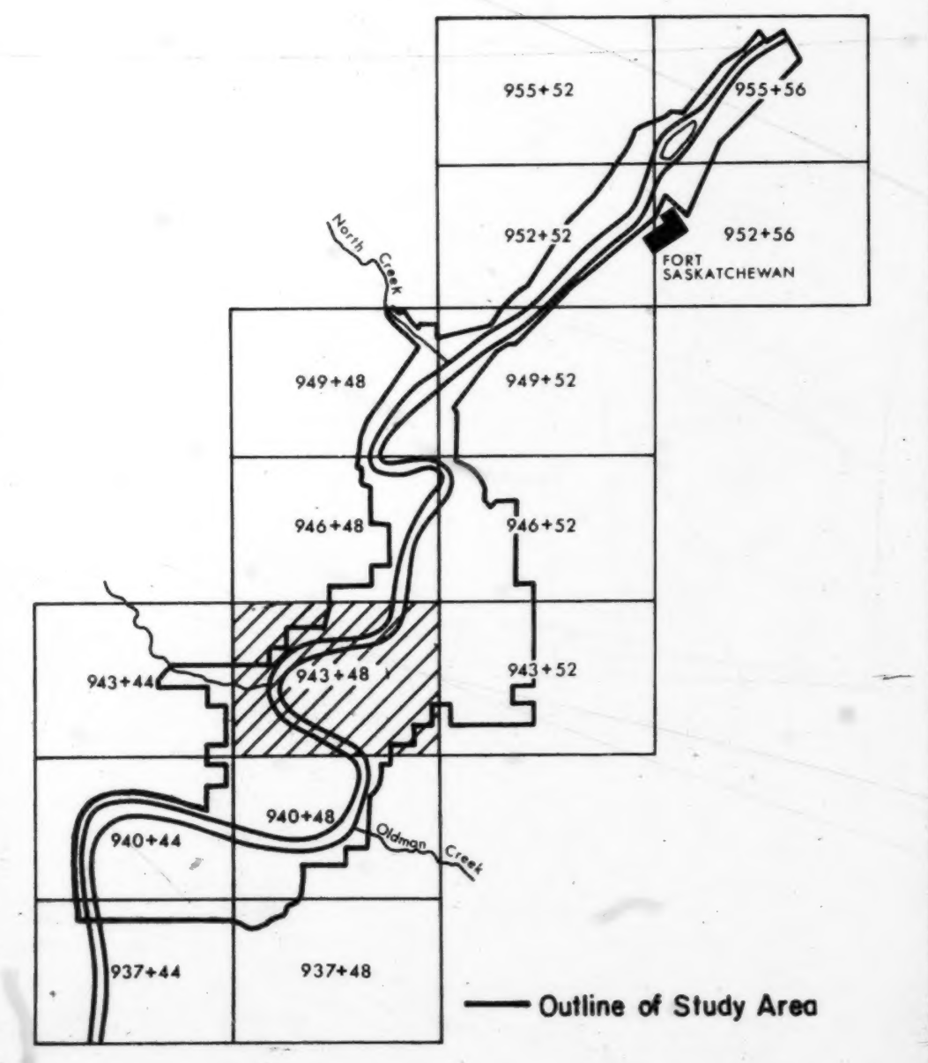
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FORT SASKATCHEWAN
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Oldman Creek
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Outline of Study Area

Scale 1:5000

metres
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LEGEND

— - —	SET-BACK GUIDELINE
——	APPROXIMATE VALLEY CREST LINE
⬭	ACTIVE AND INACTIVE-YOUNG SLOPE MOVEMENTS
⋯	INACTIVE-MATURE SLOPE MOVEMENTS

Cadastral Number: 943+48
53 & 54-23-W4

Figure 106

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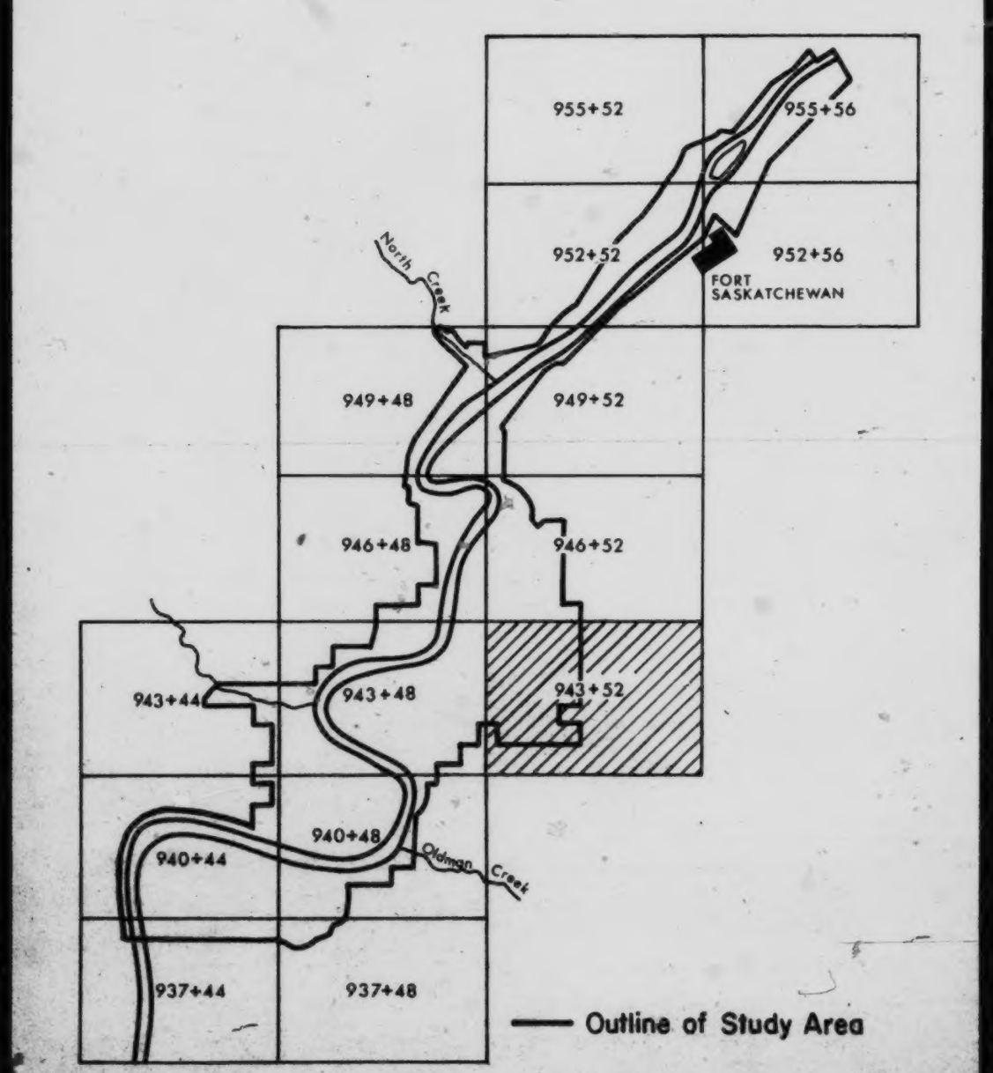
FORT SASKATCHEWAN
RESTRICTED DEVELOPMENT AREA
MAP

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS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Oldman Creek
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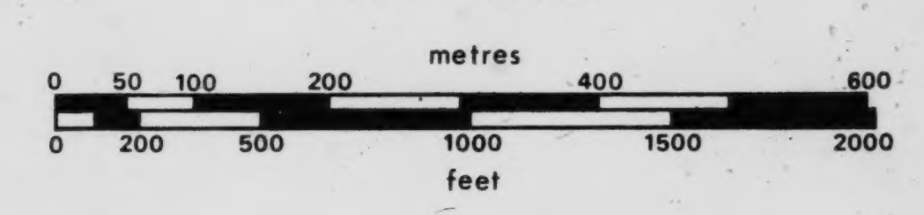
— Outline of Study Area

Scale 1:5000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——	APPROXIMATE VALLEY CREST LINE
⬭	ACTIVE AND INACTIVE-YOUNG SLOPE MOVEMENTS
⋯	INACTIVE-MATURE SLOPE MOVEMENTS

Cadastral Number: 943 + 52
53 & 54 - 23 - W4

Figure 107

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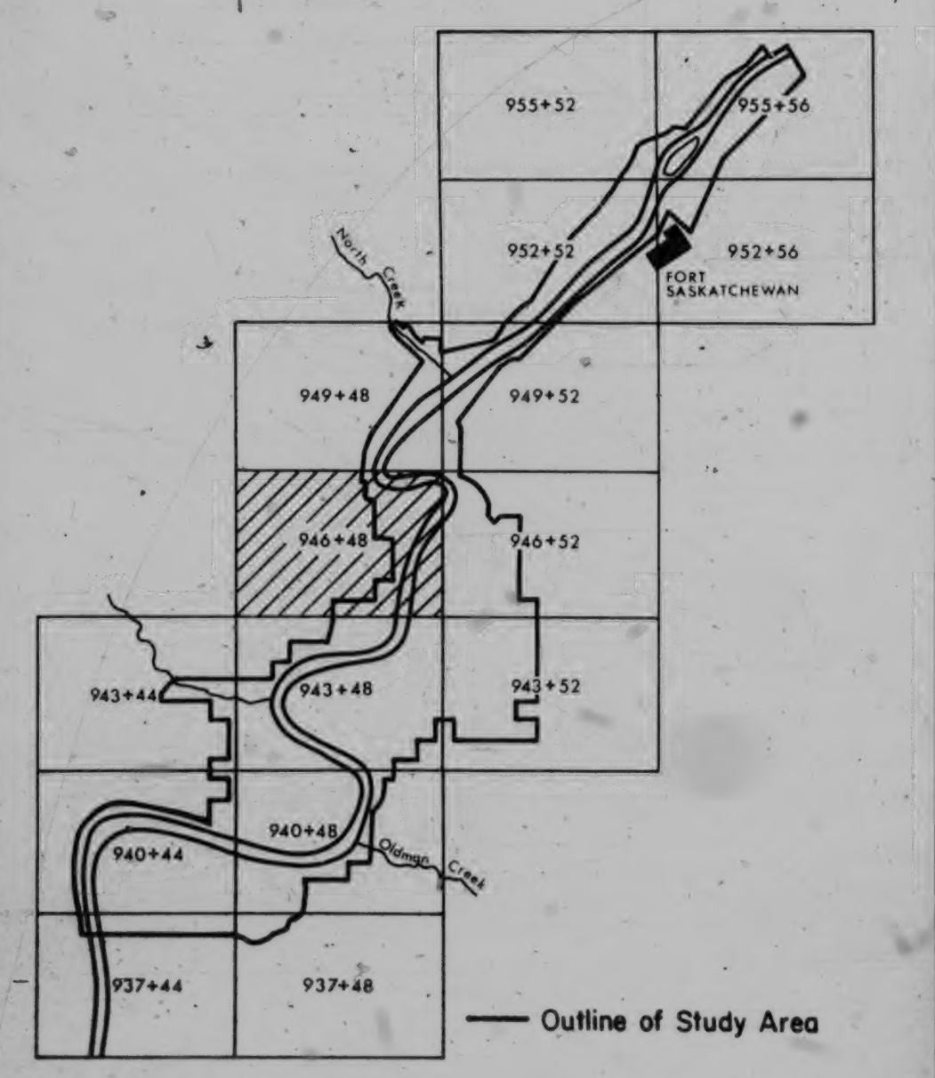
FORT SASKATCHEWAN
RESTRICTED DEVELOPMENT AREA
MAP

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS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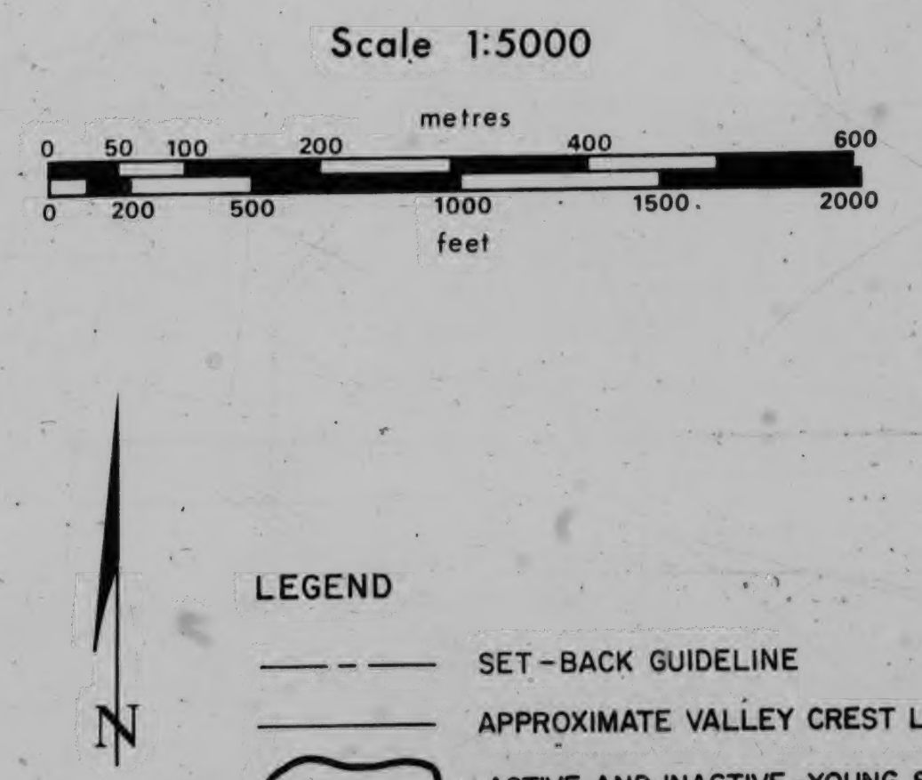
Outline of Study Area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LEGEND

SET-BACK GUIDELINE

APPROXIMATE VALLEY CREST LINE

ACTIVE AND INACTIVE-YOUNG SLOPE MOVEMENTS

INACTIVE-MATURE SLOPE MOVEMENTS

Cadastral Number: 946 + 48
54-23-W4

Figure 108

Prepared for: ALBERTA ENVIRONMENT – 1984
Prepared by: ECOLOGICAL LAND SURVEYS LTD.

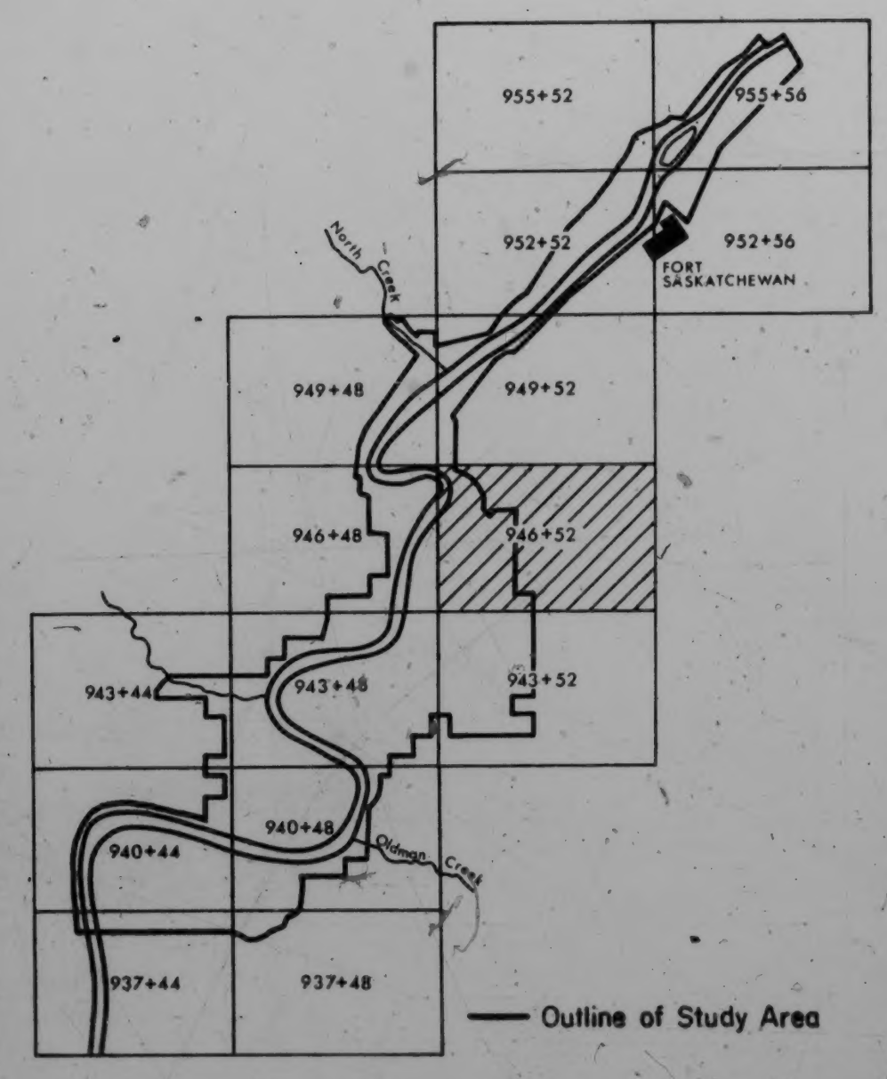
FORT SASKATCHEWAN
RESTRICTED DEVELOPMENT AREA
MAP

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS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943+48
943+52
940+44
940+48
Oldman Creek
937+44
937+48

— Outline of Study Area

Scale 1:5000

metres
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1000
1500
2000
feet

LEGEND

— — —	SET-BACK GUIDELINE
———	APPROXIMATE VALLEY CREST LINE
⬭	ACTIVE AND INACTIVE-YOUNG SLOPE MOVEMENTS
⋯	INACTIVE-MATURE SLOPE MOVEMENTS

Cadastral Number: 946 + 52
54-23-W4

Figure 109

Prepared for: ALBERTA ENVIRONMENT – 1984
Prepared by: ECOLOGICAL LAND SURVEYS LTD.

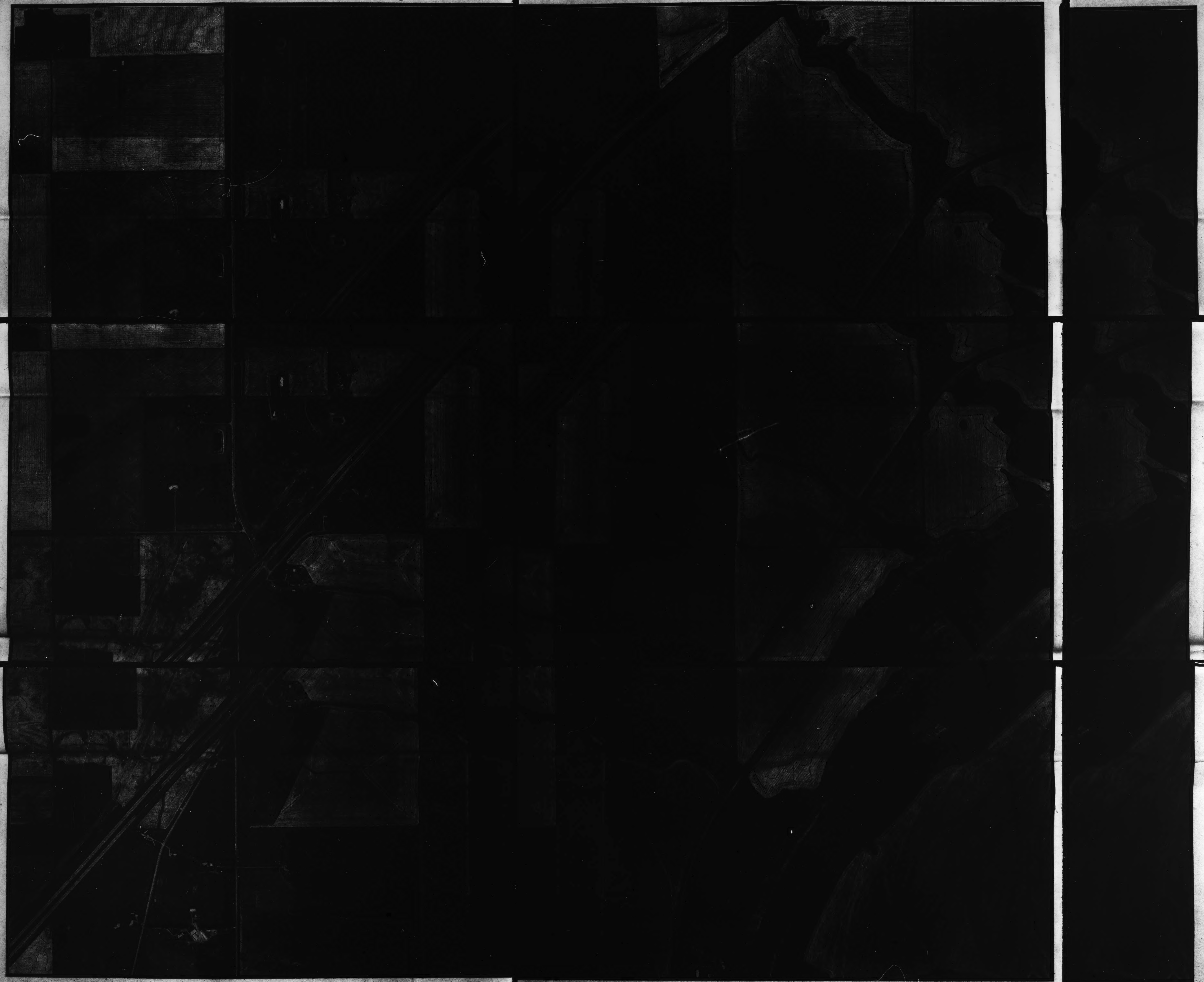
FORT SASKATCHEWAN
RESTRICTED DEVELOPMENT AREA
MAP

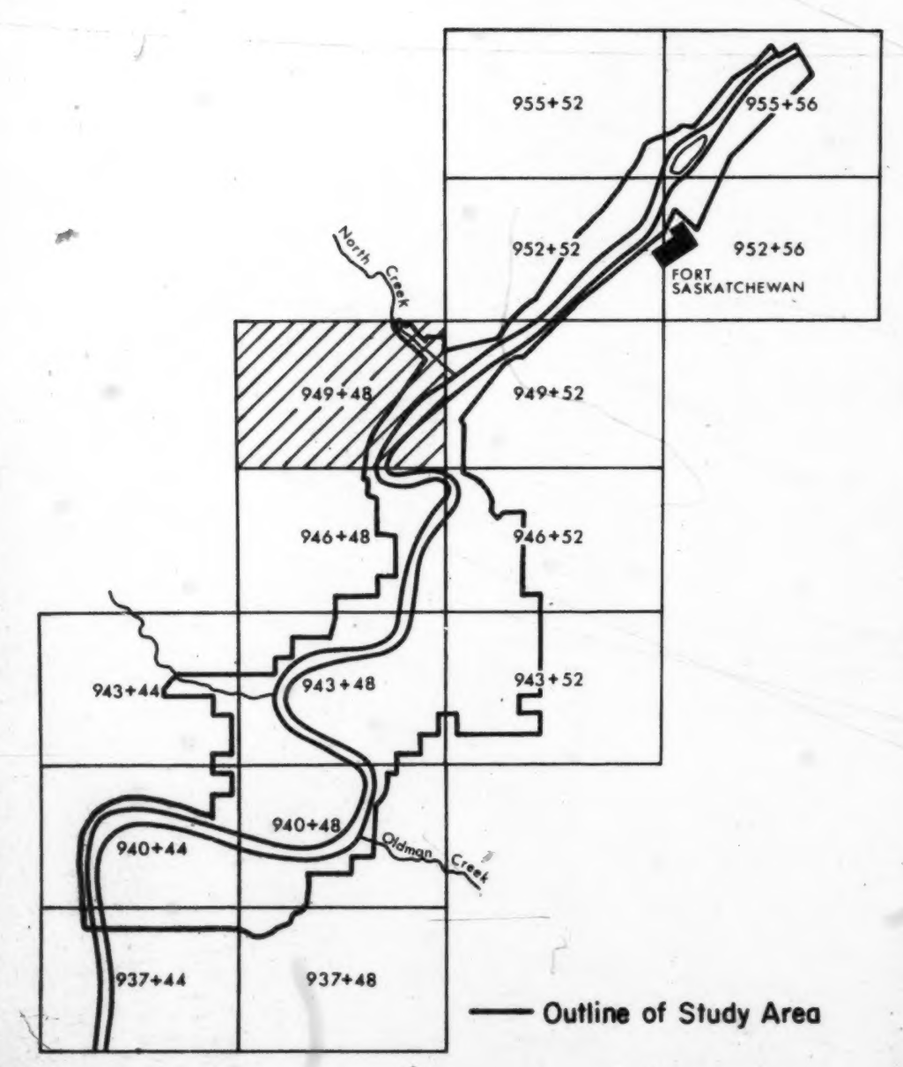
NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS

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952+56
FORT SASKATCHEWAN
North Creek
949+48
949+52
946+48
946+52
943+44
943+48
943+52
940+44
940+48
Oldman Creek
937+44
937+48
Outline of Study Area

Scale 1:5000

metres
0 50 100 200 400 600
0 200 500 1000 1500 2000
feet
N

LEGEND

- SET-BACK GUIDELINE
- APPROXIMATE VALLEY CREST LINE
- ACTIVE AND INACTIVE-YOUNG SLOPE MOVEMENTS
- INACTIVE-MATURE SLOPE MOVEMENTS

Cadastral Number: 949+48
54-23-W4

Figure 110

Prepared for: ALBERTA ENVIRONMENT – 1984
Prepared by: ECOLOGICAL LAND SURVEYS LTD.

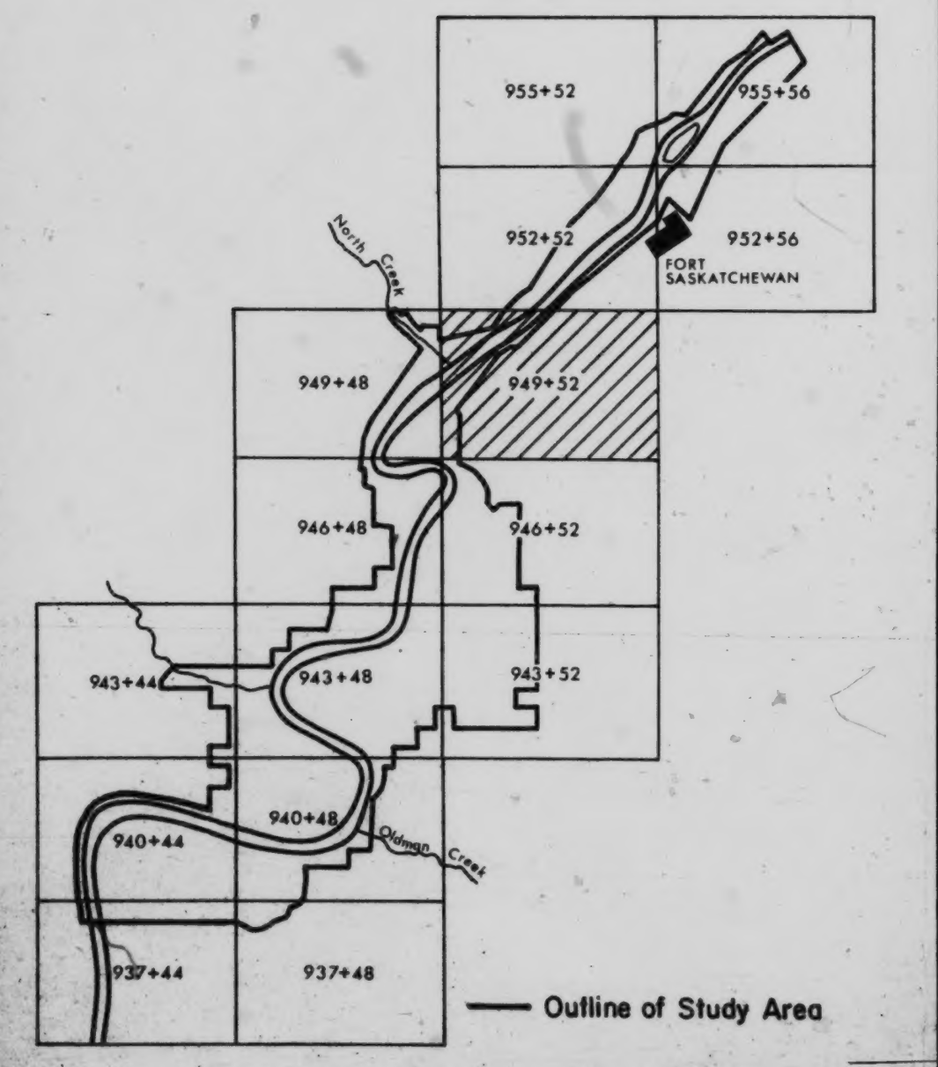
FORT SASKATCHEWAN
RESTRICTED DEVELOPMENT AREA
MAP

NORTH SASKATCHEWAN RIVER SLOPE STUDY

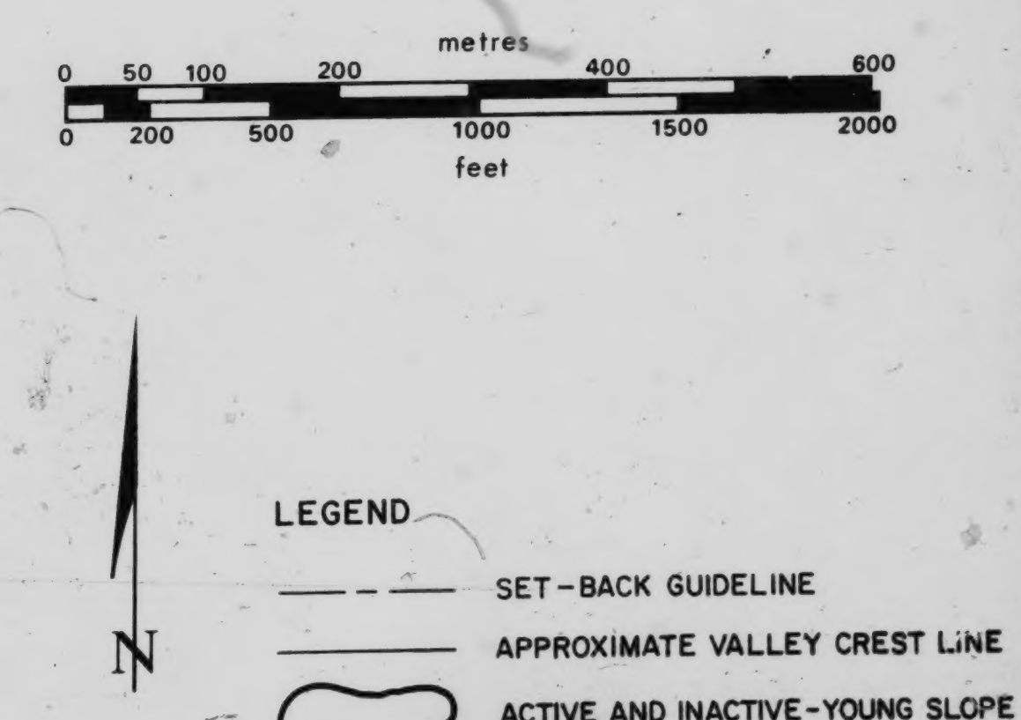
SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS


955+52
955+56
952+52
952+56
North Creek
FORT SASKATCHEWAN
949+48
949+52
946+48
946+52
943+44
943+48
943+52
940+44
940+48
Oldman Creek
937+44
937+48
Outline of Study Area

Scale 1:5000


metres
0
50
100
200
400
600
0
200
500
1000
1500
2000
feet
N

LEGEND

— — —	SET-BACK GUIDELINE
———	APPROXIMATE VALLEY CREST LINE
⬭	ACTIVE AND INACTIVE-YOUNG SLOPE MOVEMENTS
⋯	INACTIVE-MATURE SLOPE MOVEMENTS

Cadastral Number: 949+52
FORT SASKATCHEWAN

Figure 111

Prepared for: ALBERTA ENVIRONMENT – 1984
Prepared by: ECOLOGICAL LAND SURVEYS LTD.

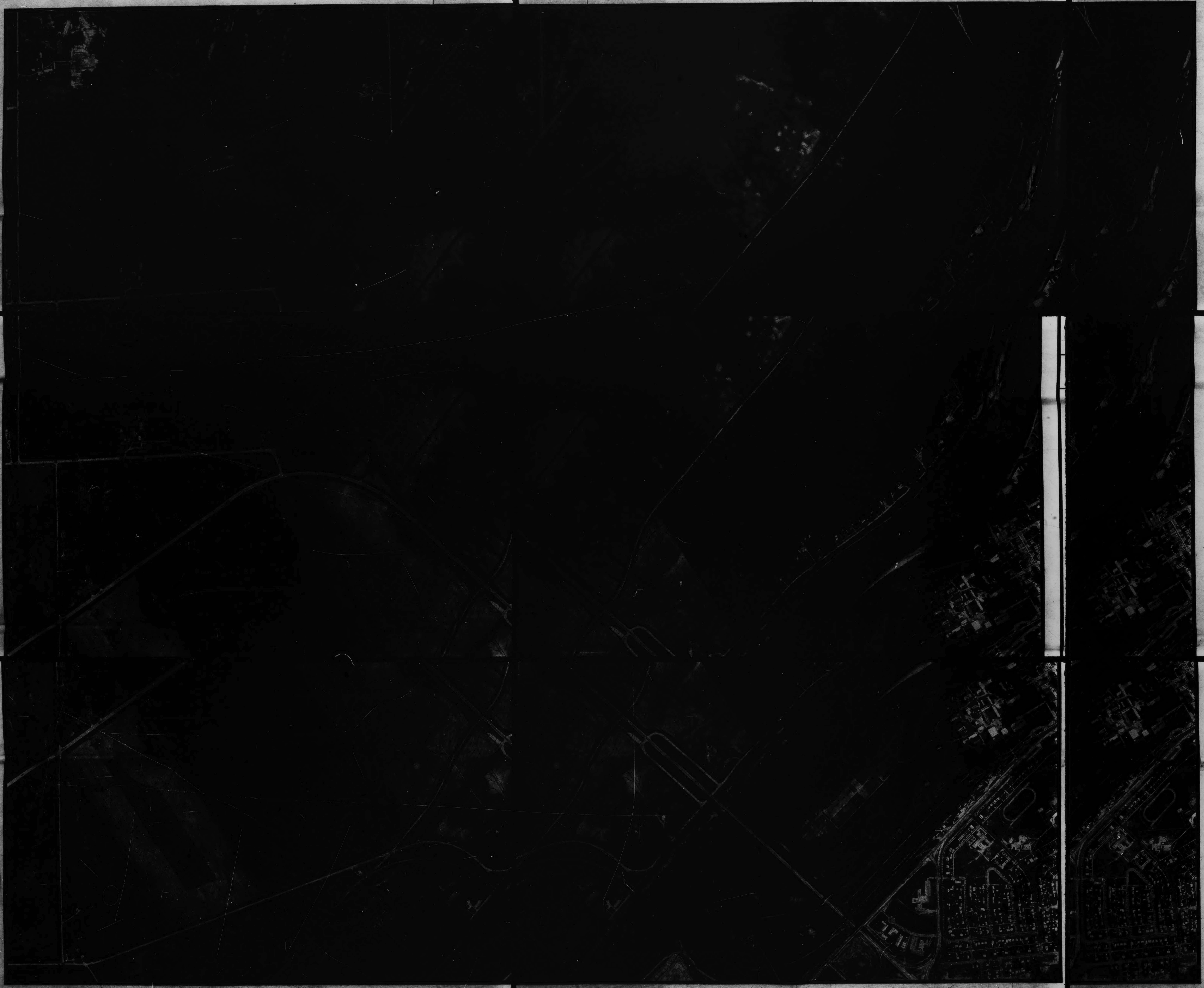
FORT SASKATCHEWAN
RESTRICTED DEVELOPMENT AREA
MAP

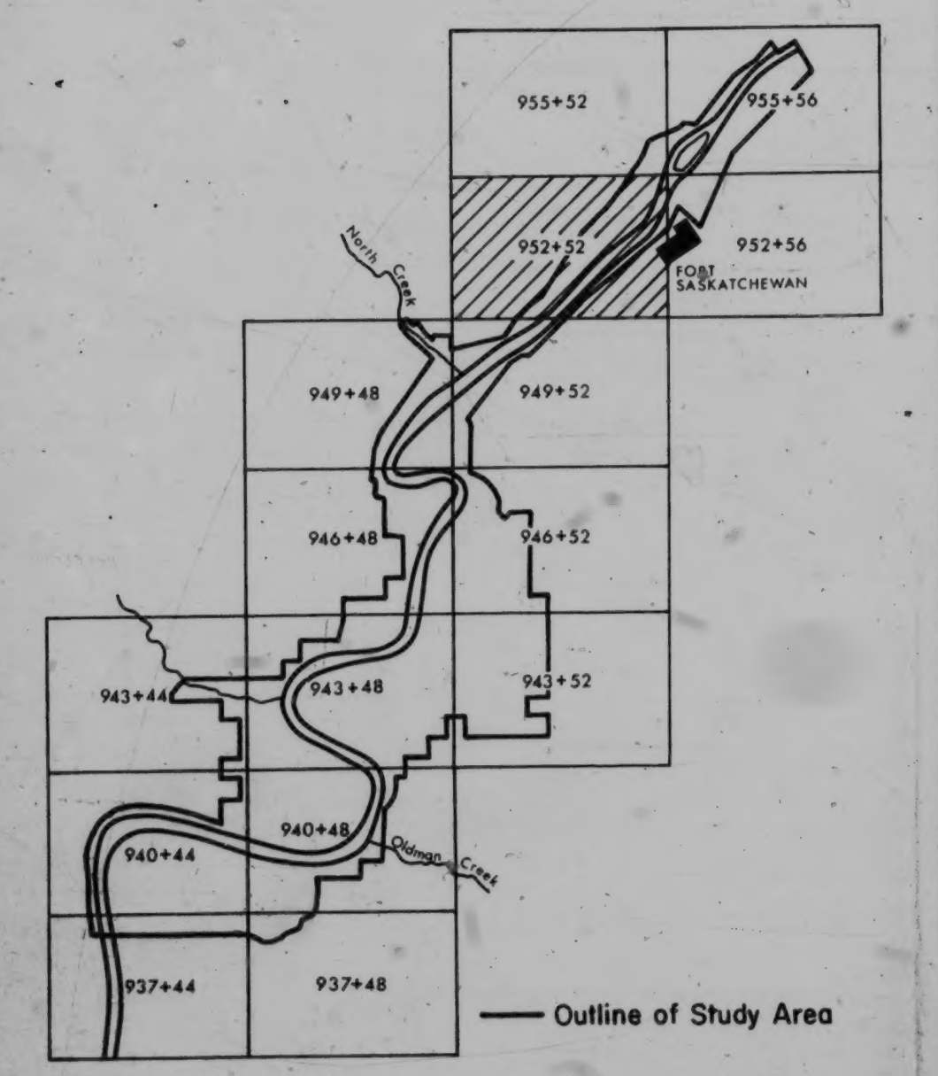
NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS




955+52
955+56
952+52
952+56
FORT SASKATCHEWAN
North Creek
949+48
949+52
946+48
946+52
943+44
943+48
943+52
940+44
940+48
Oldman Creek
937+44
937+48
Outline of Study Area

Scale 1:5000

metres
0 50 100 200 400 600
0 200 500 1000 1500 2000
feet
N

LEGEND

— —	SET-BACK GUIDELINE
⌐—	APPROXIMATE VALLEY CREST LINE
⬭	ACTIVE AND INACTIVE-YOUNG SLOPE MOVEMENTS
⋯	INACTIVE-MATURE SLOPE MOVEMENTS

Cadastral Number: 952 + 52
FORT SASKATCHEWAN

Figure 112

Prepared for: ALBERTA ENVIRONMENT — 1984
Prepared by: ECOLOGICAL LAND SURVEYS LTD.

268

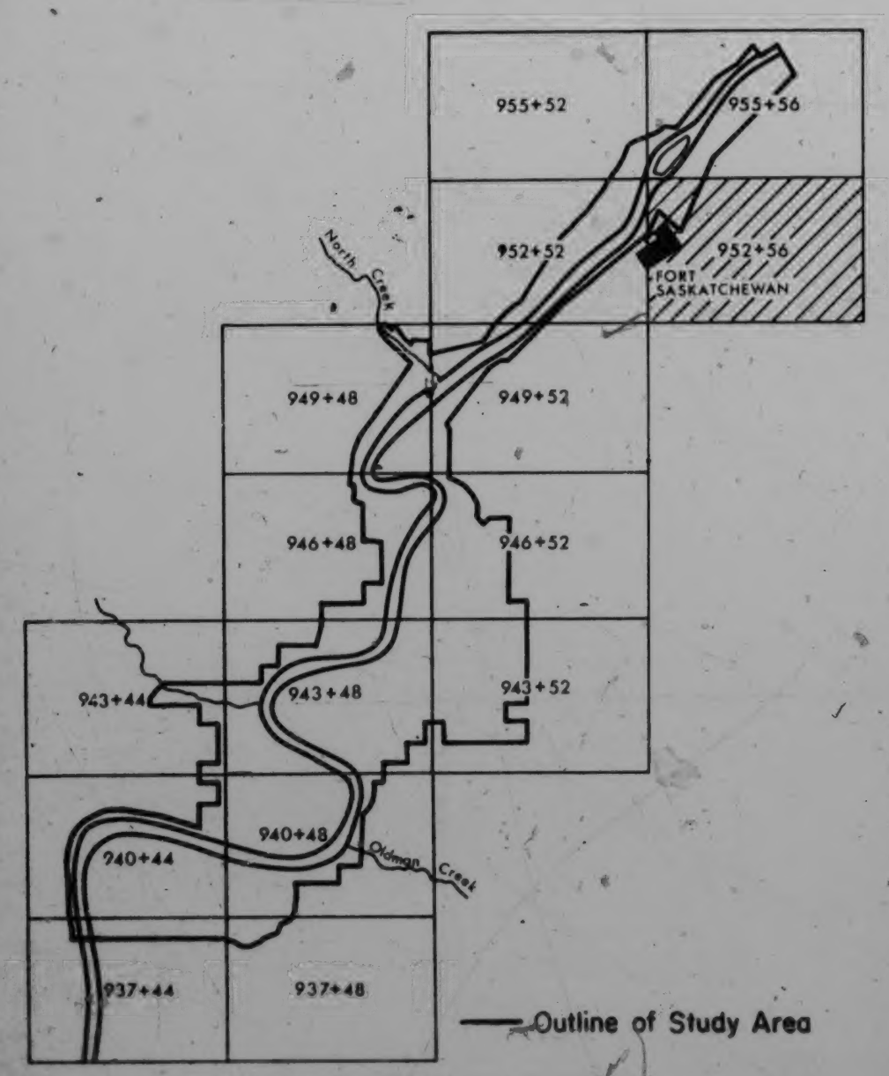
FORT SASKATCHEWAN
RESTRICTED DEVELOPMENT AREA
MAP

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS


955+52
955+56
952+52
952+56
FORT SASKATCHEWAN
North Creek
949+48
949+52
946+48
946+52
943+44
943+48
943+52
940+44
940+48
Oldman Creek
937+44
937+48
Outline of Study Area

Scale 1:5000

metres
0 50 100 200 400 600
0 200 500 1000 1500 2000
feet
N

LEGEND

- — — — SET-BACK GUIDELINE
- ——— APPROXIMATE VALLEY CREST LINE
- ⬭ ACTIVE AND INACTIVE-YOUNG SLOPE MOVEMENTS
- ⬚ INACTIVE-MATURE SLOPE MOVEMENTS

Cadastral Number: 952+56
FORT SASKATCHEWAN

Figure 113

Prepared for: ALBERTA ENVIRONMENT – 1984
Prepared by: ECOLOGICAL LAND SURVEYS LTD.

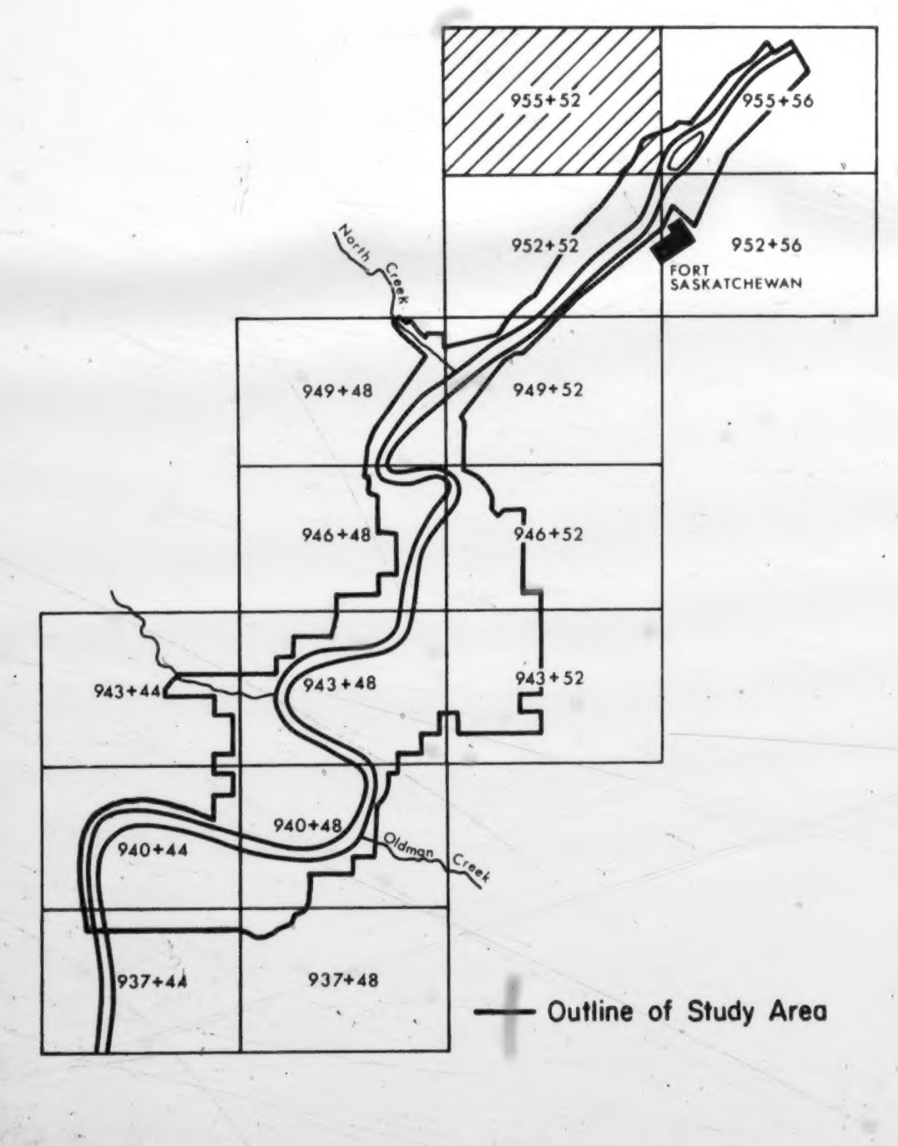
FORT SASKATCHEWAN
RESTRICTED DEVELOPMENT AREA
MAP

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS


955+52
955+56
952+52
952+56
FORT SASKATCHEWAN
North Creek
949+48
949+52
946+48
946+52
943+44
943+48
943+52
940+44
940+48
Oldman Creek
937+44
937+48

Outline of Study Area

Scale 1:5000

metres
0 50 100 200 400 600
0 200 500 1000 1500 2000
feet
N

LEGEND

- SET-BACK GUIDELINE
- APPROXIMATE VALLEY CREST LINE
- ACTIVE AND INACTIVE-YOUNG SLOPE MOVEMENTS
- INACTIVE-MATURE SLOPE MOVEMENTS

Cadastral Number: 955+52
FORT SASKATCHEWAN

Figure 114

Prepared for: ALBERTA ENVIRONMENT – 1984
Prepared by: ECOLOGICAL LAND SURVEYS LTD.

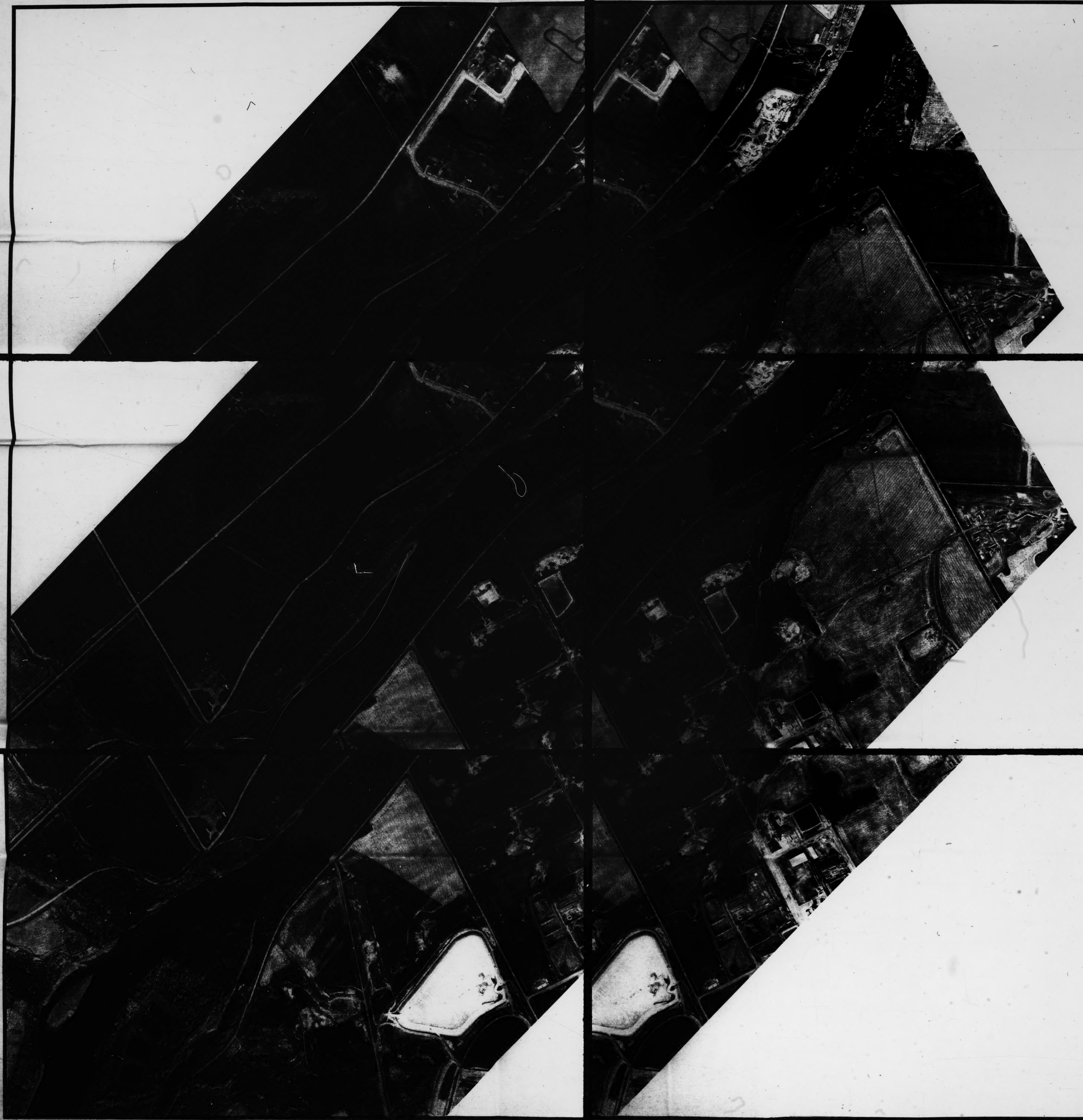
FORT SASKATCHEWAN
RESTRICTED DEVELOPMENT AREA
MAP

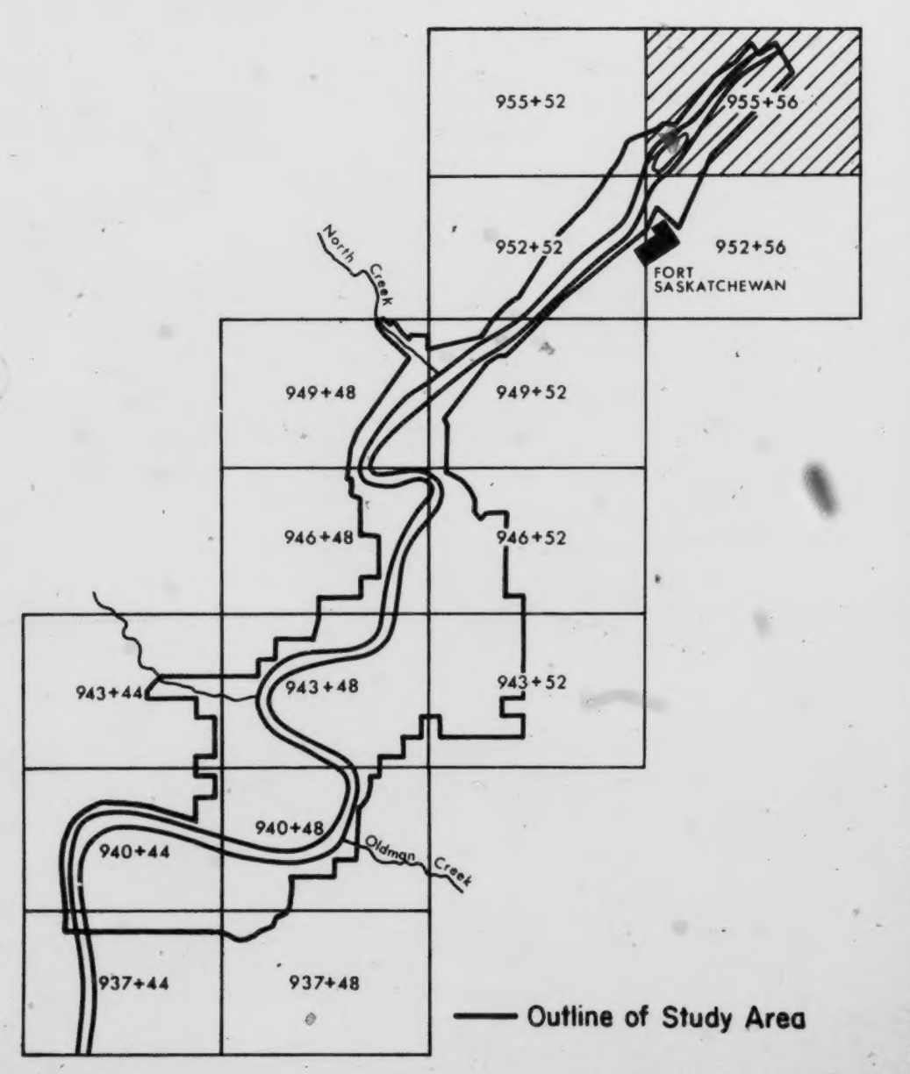
NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS

NORTH SASKATCHEWAN RIVER SLOPE STUDY

SET-BACK GUIDELINES
AND
SLOPE MOVEMENT LOCATIONS




955+52
955+56
952+52
952+56
FORT SASKATCHEWAN
North Creek
949+48
949+52
946+48
946+52
943+44
943+48
943+52
940+44
940+48
Oldman Creek
937+44
937+48
Outline of Study Area

Scale 1:5000

metres
0 50 100 200 400 600
0 200 500 1000 1500 2000
feet
N

LEGEND

- — – — SET-BACK GUIDELINE
- ——— APPROXIMATE VALLEY CREST LINE
- ⬭ ACTIVE AND INACTIVE-YOUNG SLOPE MOVEMENTS
- ⋯ INACTIVE-MATURE SLOPE MOVEMENTS

Cadastral Number: 955 + 56
FORT SASKATCHEWAN

Figure 115

Prepared for: ALBERTA ENVIRONMENT – 1984
Prepared by: ECOLOGICAL LAND SURVEYS LTD.